Sedimentology and Structural Geology of the Neogene Formations, South East Sabah.

by

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C. TABLE OF CONTENTS

LIST OF FIGURES

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Every work we do is linked directly or indirectly to many different aspects, circumstances and people. Aspects which we try to understand, work on and come to a conclusion, circumstances which motivate us and people who help us and guide us to achieve what we are intend to.

Recollecting the near past events, I am deeply indebted to the people who were responsible for the successful completion of my second 2 semesters Final Year Project course called by UTP as FYP1 and FYP2 from January until August 2014.

To begin with I want to express my special sense of gratitude and sincere thanks to Miss Nor Sara Izzatti binti Bashah, an expert in sedimentology who became the instrumental and key person during the whole Final Year project period. As my FYP Supervisor, she has guided me going through the different dimensions of the geology aspects. Every single words and advice she told me has become the source of motivation and inspiration for me in going through a successful project. Every new knowledges she taught to me was very significant in becoming a successful future geologist or geoscientists.

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To wrap up my appreciation, thanks to all my friends and anyone involved in helping me and advising me throughout the whole project.

ABSTRACT

Sabah, situated in the northern part of the island of Borneo, and lying adjacent to actively moving plates in South East Asia region has a complex geological history. The well-developed compressive and extensional structures are the manifestation of several regional tectonic events in Sabah since the Early Tertiary. The area of interest in this project is the Neogene formations specifically the Kalabakan and Kapilit formations located in South East of Sabah. The highlights of this study would be on the structural geology and sedimentology of the area.

In structural perspective, the outcome of the project suggested that the Kapilit and Kalabakan area is affected by series of shearing of wrench faults. In addition, by sedimentology point of view, the area has been concluded as from marine origin through extensive interpretation of the formations' outcrops during the field work. Thin section analysis, rose diagram and lineament analysis through satellite images are lists of methods used in order to understand more on how these Neogene formations was geologically shaped in South East Sabah.

CHAPTER 1

INTRODUCTION

1.1. Background of Study

Sabah occupies a central position between three marginal basins: the Sulu, Celebes and South China Seas. Sabah located in the Northern Part of Borneo, and lying nearby to actively moving plates in the Southeast Asian region, has a complex geological history and structures. The extrusion of continental fragments from Asia driven by India's collision, large scale rotation of Borneo, and effects of collision of Australia with South East Asia have all been impacted in the development of Borneo (Hall et al., 2002). The circular basins formation in southeast Sabah is still debatable in relation to the plate tectonic history. This project is more related to Neogene formations in Sabah, where more attention will be given to Kapilit and Kalabakan formation located in South East Sabah. Sedimentology and structural geology of these two areas is the main agenda of this project.

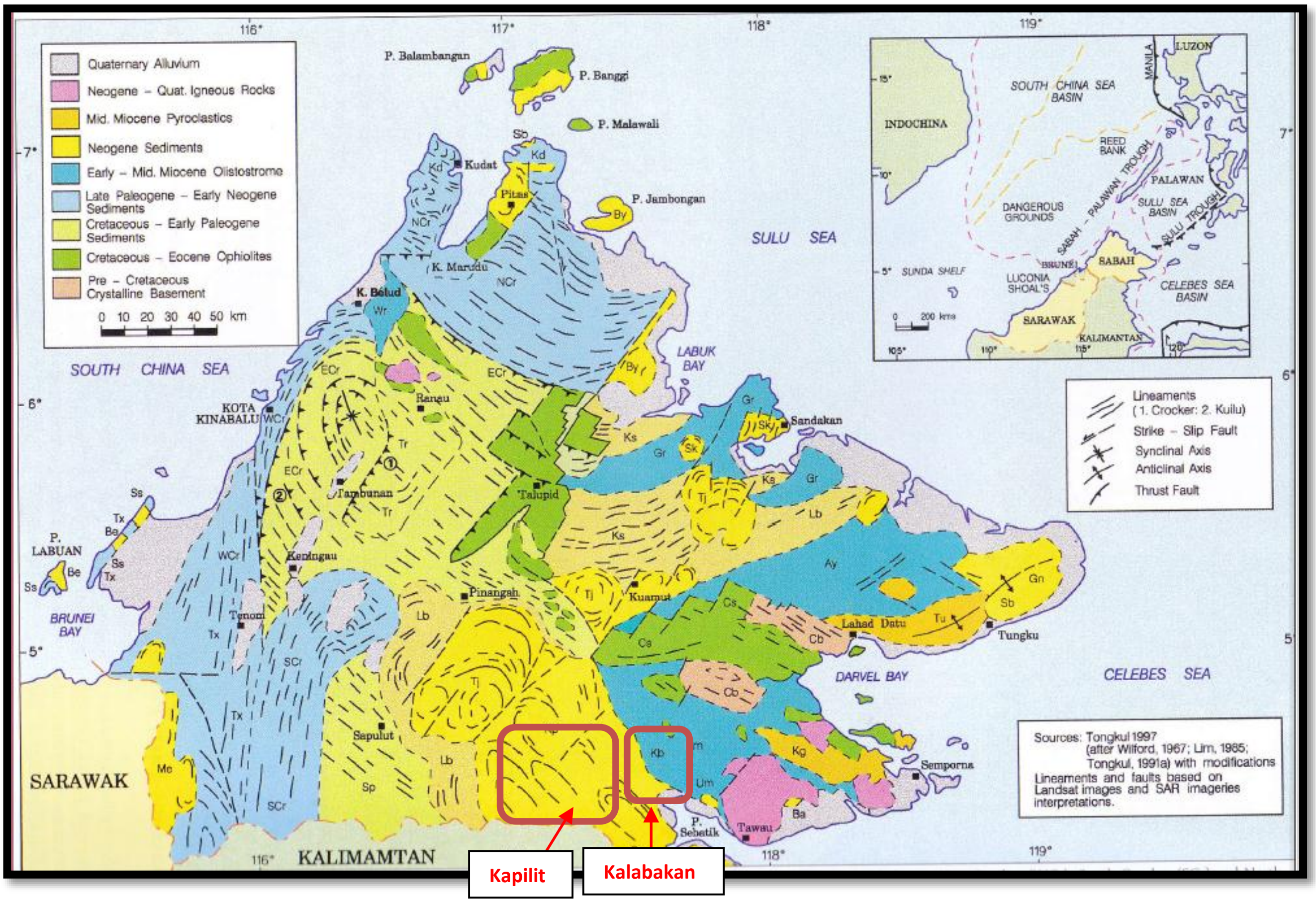


Figure 1: Tectonic Map of onshore Sabah specifically at Kapilit and Kalabakan formation based on (Tongkul, 1993)

1.2. Problem Statement

The problem statement of this project is to find the answer of what kind of sedimentation process had happened and structural geology formed in relative to the Neogene formation specifically Kapilit and Kalabakan formation in Sabah.

1.3. Objectives

The objectives of this project are listed as below:-

- To conduct a detailed study on general and structural geology of Neogene formation specifically Kapilit and Kalabakan formation.
- To analyze and understand the sedimentology of rock in relative to the Neogene formation and the process that result in their deposition.
- To describe the lithology of the rocks; description of physical characteristics visible at outcrops and the mineralogy

1.4. Scope of Study

This final year project called "Sedimentology and Structural Geology of Neogene Formation" is divided into several main scopes. The first scopes will be on the geology of the Kapilit and Kalabakan formation. A detailed road traverse map and cross-sectional map has been conducted on certain appropriate scale by using several techniques. During the field work, rock samples of the Neogene formation have been collected. Post-fieldwork scope covers lineament analysis using satellite images and topographic map, thin section analysis and lastly interpretation of outcrops with help of rose diagrams and several fieldwork data.

1.5. Relevancy of the Project

The project is relevant to be done because it was closely related to what I've learned during the last 3 years in UTP. Finishing my 6th semesters last year in this Petroleum Geoscience program has given me some basic geological knowledge and skills to do this project. Furthermore, this project will help me a lot in understanding the structural geology and sedimentology of the Neogene formation in Sabah. In addition, by studying the formation of the circular basin it will shed some lights on the tectonic history of onshore and offshore Sabah.

Apart from that, this project was given to me to polish my geological skills in the field on how to produce a good geological map and to give me deeper understanding of the process related to sedimentation of the Neogene formation. It also helps me in term of having good professional communication skills as I need to communicate to ask my project supervisor, professors and lab technician if I encounter any problems throughout the project.

1.6. Feasibility of the Project

The time frame given by UTP Final Year Project (FYP) committee was actually decent and considerable to be fit enough for me to finish up the project.

In terms of the accessibility of the formation during the field trip, outcrops for this research is located along Kalabakan-Sapulut road. Five days fieldwork was done to study these outcrops. Several experiments and laboratory tests will be conducted tailored to the equipment available in UTP.

CHAPTER 2

LITERATURE REVIEW

2.1. Tectonic Evolution of Sabah

Tectonic Evolution in Sabah can be described based on the geologic time frame as follows:-

2.1.1. Pre-Cretaceous

During Pre-Cretaceous, Sabah Crystalline Basement has been described as ‘older metamorphosed oceanic basement with rare acid intrusive rocks (Tongkul, 1991a). The acid igneous rocks and the metamorphic basement represent different tectonic history and origin.

2.1.2. Early Cretaceous-Early Eocene

At this time, ‘new oceanic basement’ which is actually the ophiolite complex forms the basement of the thick sedimentary systems of Sabah (Hutchison, 1989). Tongkul (1991a) said that the ophiolite complex consists of pelagic sediments, including radiolarian cherts and *Globotruncana*-bearing limestones. In the Eocene time, the ophiolite complex and the argillaceous sedimentary units we all later deformed and uplifted (Bernard et al., 1990; Hutchinson,1992b; Tongkul 1991a).

The NW-SE extension in the southern continental margin of China, and the anticlockwise rotation of the continental basement of Borneo (Kalimantan) and West Borneo Basement has occurred during this time. (Tongkul, 1997; Taylor and Hayes 1983; Hinz et al., 1991) The southeastward subduction of the proto-South China Sea oceanic lithosphere under the NW margin of Borneo has also been described as related to the Eocene deformation.

The opposing movements of two continental masses from the NW (the southern continental margin of China) and the SE (the Borneo microcontinental plate) are due to the closing of the deep trough of the proto-South China Sea Basin or ‘Rajang Sea’.

2.1.3. Oligocene

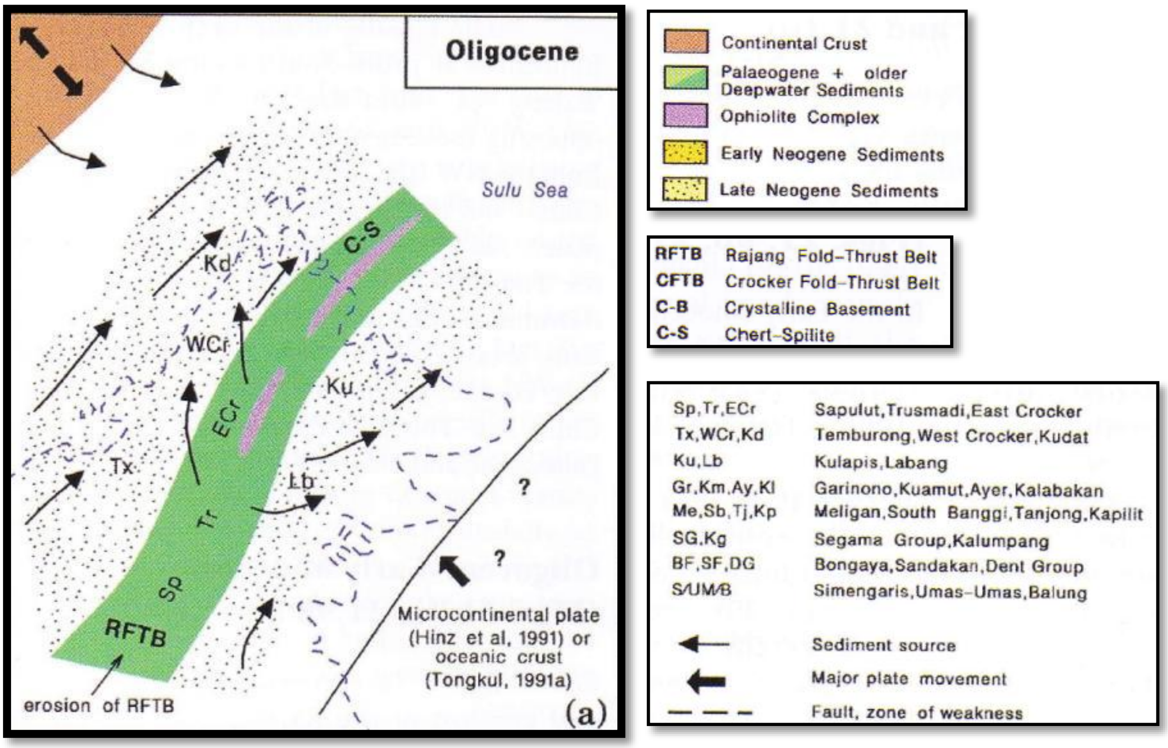


Figure 1 (a): Oligocene Palaeogeographical and tectonic sketches of Sabah based on (Tongkul, 1991a)

After Late Eocene deformation, based on Figure 1(a), uplift and erosion of the Rajang Fold Thrust Belt (RFTB) fed new depocentres to the west and east (Paleogene Basins) (Tongkul, 1991a). Initial uplift of the Temburong (Te) and West Crocker (WCr) formations are result of the opening of the South China Sea due to Southward movement of the NW Sabah plate.

2.1.3. Late Oligocene-Early Miocene

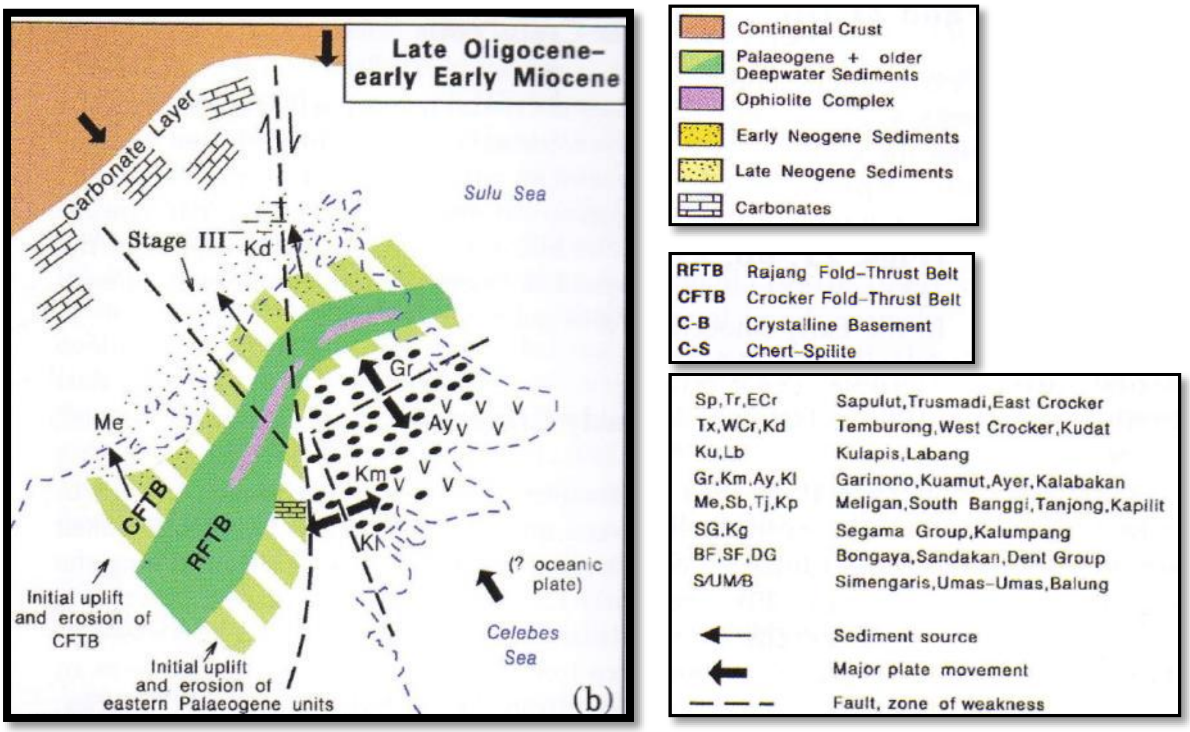


Figure 1 (b): Late Oligocene-Early Miocene Palaeogeographical and tectonic sketches of Sabah based on (Tongkul, 1991a)

Based on Figure 1 (b), at the North (Stage III and Kudat) deep marine clastic deposition continued while at the South, Melingan (Me) shallow marine were deposited. Initial uplift of Crocker Fold-Thrust Belt (CFTB) happened due to imminent intense deformation and widespread carbonates deposition as in the Figure 1 (b).

During this time also, two rift zones which are Sandakan rift (NE trending) and Taranakan (SE trending) began to form (Tongkul, 1991a).

2.1.4. Early Miocene-Middle Miocene

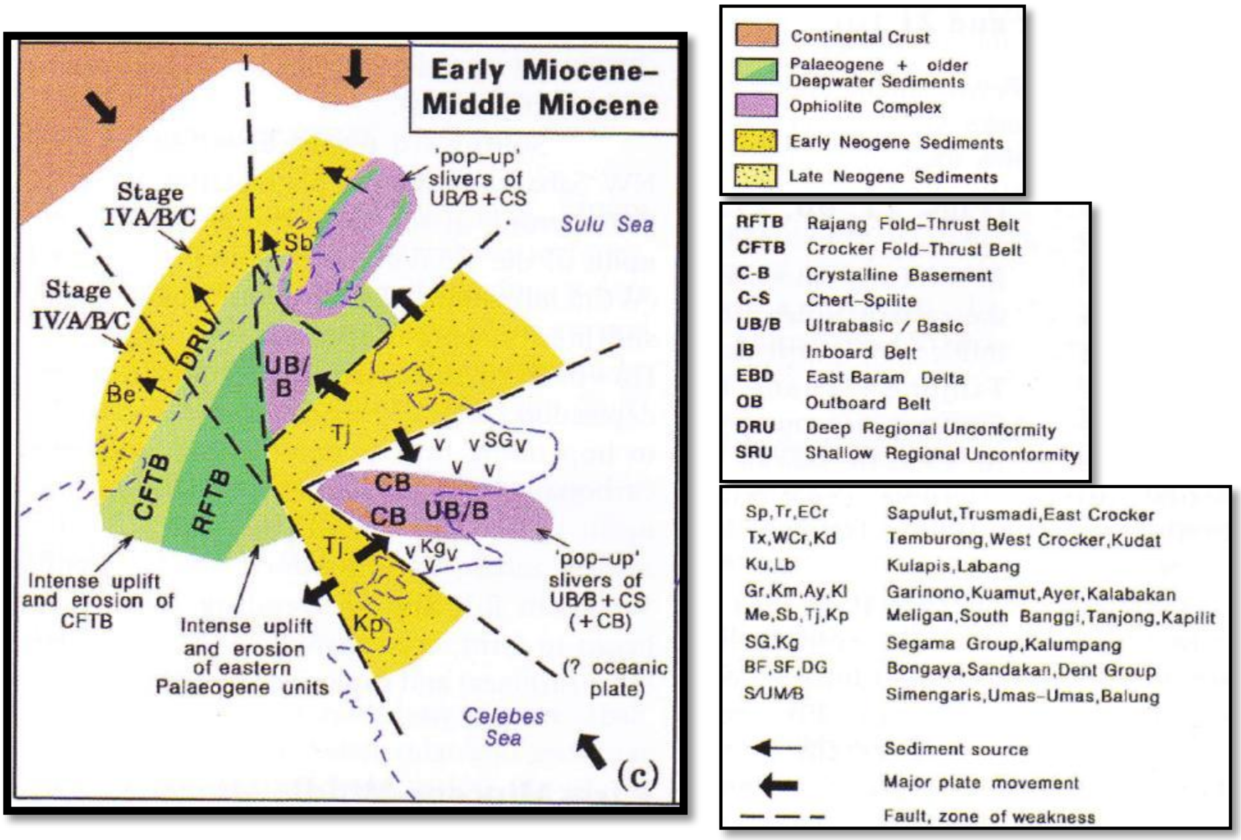


Figure 1 (c): Early Miocene-Middle Miocene Palaeogeographical and tectonic sketches of Sabah based on (Tongkul, 1991a)

Tongkul (1991a), states that during this time, Tanjong (Tj) and Kapilit (Kp) formation begins to form due to the infilled by synrift deposits as the both Eastern Sandakan and Taranakan rift zones widened. Due to the N-S opening of the South China Sea, at the northern Sabah, Palawan and Reed Bank terrane collided with the fold belt of NW Borneo. In comparison, at the South Sabah the Celebes Sea oceanic lithosphere was subducted north-westward (Rangin et al., 1990).

As a result of this two phenomenon at North and South Sabah, these collision caused the bending of Crocker Fold-Thrust Belt (CFTB). Also according to Tongkul (1991), the eastern and central Sabah ophiolitic complex (CS, UB/B) were dig up as ‘pop-up’slivers.

2.1.5. Late Miocene-Early Pliocene

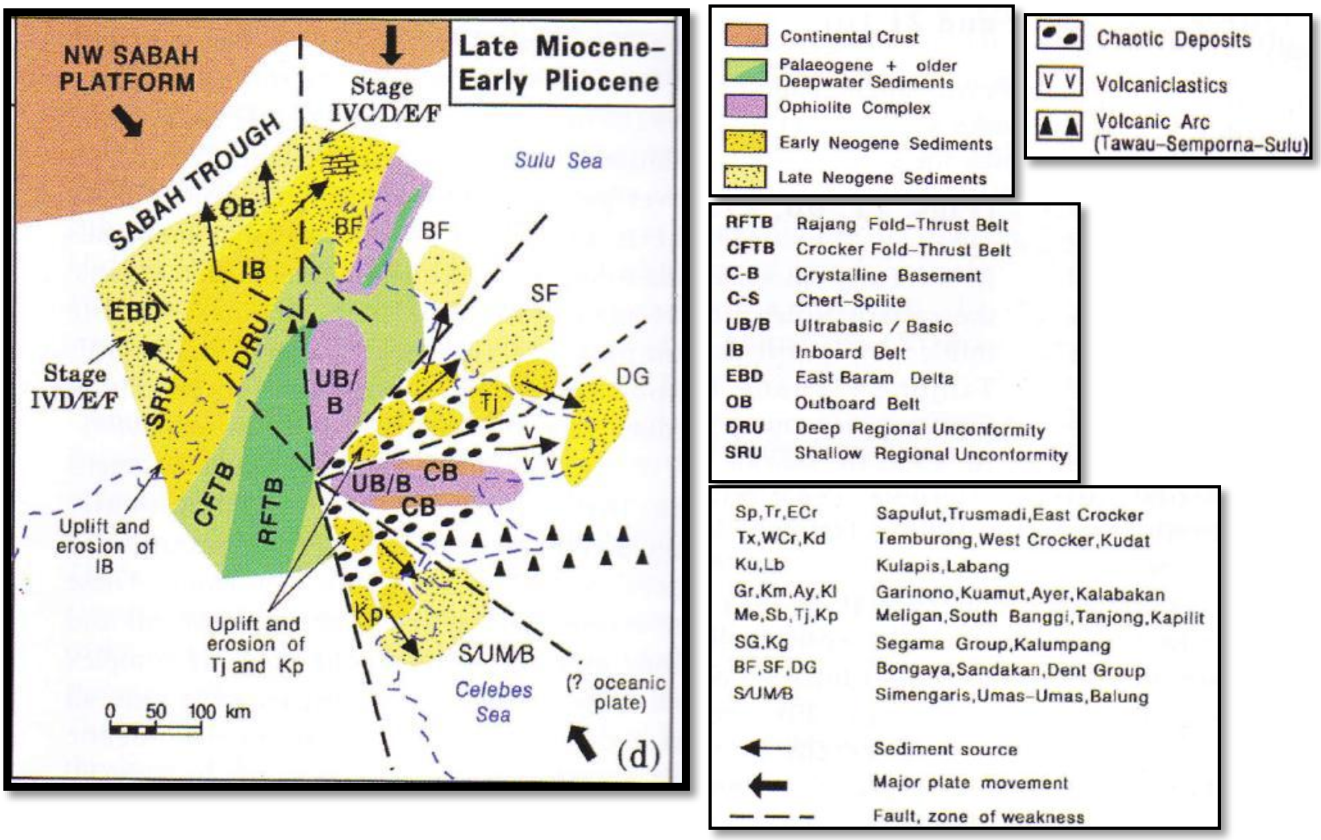


Figure 1 (d): Late Miocene-Early Pliocene Palaeogeographical and tectonic sketches of Sabah based on (Tongkul, 1991)

Hazebroek and Tan (1993) claim that the Inboard Belt (IB) were uplifted and eroded to feed new depocentres which are Outboard Belt (OB) and East Baram Delta (EBD). The Shallow Regional Unconformity SRU, is the major erosional surface during this time.

Synrift deposits were formed into circular and sub-circular shapes in Eastern Sabah that maybe caused by both shale diapiric movement and wrench faulting. Considerable sediment thickness formed at East Sandakan Sub-basin. From Late Miocene to Quaternary, a new phase of volcanic activities and igneous intrusion (Kinabalu) occurred.

2.2. Stratigraphy of Kalabakan and Kapilit Formation, Sabah

2.2.2. Kalabakan formation

According to Balaguru & Nichols (2004) Kalabakan formation has very similar characteristics to the mudstone of Unit I of Tanjong formation. The Kalabakan formation is located in the Kalabakan valley and up to the upper part of the Tiagau area with a thick unit of grey mudstone and siltstone exposed. The new mapping by Balaguru & Nichols (2004) has indicated that Kalabakan formation is the lateral equivalent of Unit I of the Tanjong formation. An unconformity at the base of the Kalabakan formation based on Figure 2 has indicated by the chaotically deformed and indurated Kuamut/Labang formation within the Kalabakan formation (Balaguru et al., 2004).

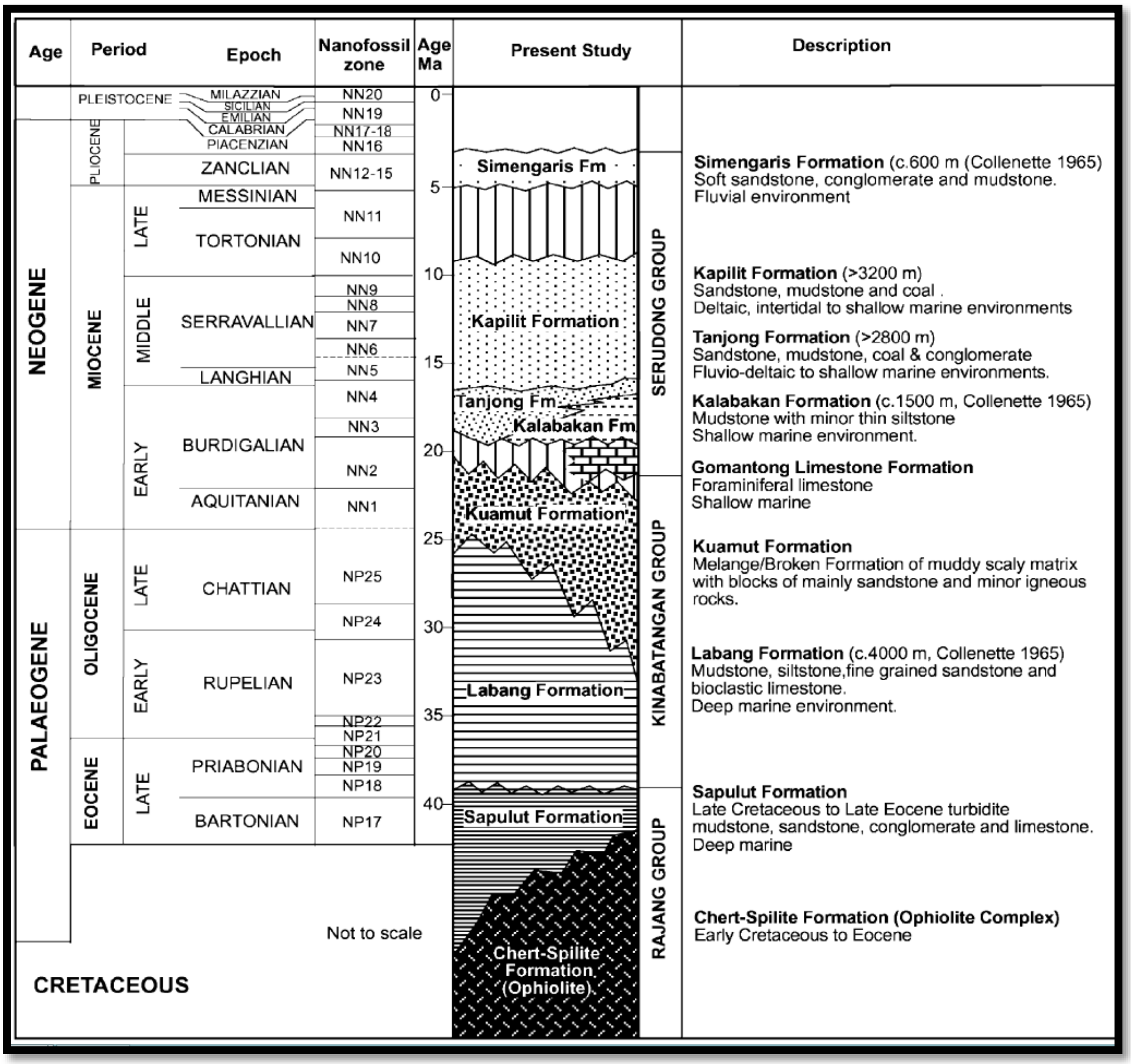


Figure 2: The Stratigraphy of Southern Sabah based on (Balaguru et al., 2004).

2.2.2. Kapilit formation

Initially, Collenette (1965) has used the term Kapilit formation for the thick sandstone and mudstone succession in the Silimpopon, Luis and Susui Valleys. Contrary, Balaguru and Nichols (2004) then came out with revised distribution of the formation which is now considered to occur in Susui, Malibau and Meliau areas.

Kapilit formation has a coarsening-upwards megasequence similar to the underlying Tanjong Formation. There are two units of subdivision for Kapilit formation, a lower mudstone and siltstone dominated sequence (Unit I), which is overlain by Unit II of sandstone, conglomerate, coal seams and carbonaceous mudstone. The newly constructed cross-sections based on Balaguru (2004) now indicate that the thickness of Unit I is 1400 m while for Unit II is 1800m (Balaguru et al., 2004).

Based on Figure 2, a bedding parallel, deeply incised erosional contact in the Tidung area of Kapilit formation overlies the Tanjong formation. The contact is seen on radar and in the field as the sequence passes from the scarp-forming outcrop of Unit II of the Tanjong formation to the less resistant mudstones of Unit I of the Kapilit formation. A distinct stratigraphic unit character of Kapilit formation can be seen as it is separated by Tanjong formation by the regional, erosional surface and the boundary that is recognised by the change from resistant sandstone to recessive-weathering mudstones in the stratigraphic succession. The Pliocene Simengaris Formation with a slight unconformity overlies the Kapilit Formation in the southeast. (Balaguru et al., 2004).

2.3. Circular Basin of Southern Sabah

The circular features are located in the most inaccessible and remote area in southern Sabah covers an area approximately 25 km long and 22 km wide. The outcrop pattern in the central Meliau is roughly circular and describes as a ‘basinal’ morphological feature. According to Balaguru, Nichols & Halls (2003), the present day outcrop pattern of Tidung, Malibau and Meliau large sub circular-to elliptical shapes synclines (the so-called ‘circular basins’) separated by narrow faulted anticlines in Southern Sabah are remnants of a single larger basins. The reason is because across the 3 areas there is evidence of similar basin evolution, sedimentation history, lithofacies distribution, palaeo-environments, sediment thickness and similar pre-Pliocene structural history.

There are a variety of models been proposed to further explain the development of the ‘circular basins’ in Sabah which previous models suggested that postulated gravitational sliding and sinking was the major factor contributing the ‘circular basin’ structural development. Recent studies shows that across the 3 areas which are Tidung, Malibau and Meliau have undergone a similar complex structural history of extension, inversion, strike slip faulting and renewed extension. The remnants of single large basin is then modified by post-depositional deformation and enhanced by erosion into near-circular to elliptical structures. Based on Figure 3, the Neogene ‘basins’ are interpreted as the product of transpressional tectonics and inversion during the latest Pliocene (Balaguru et al., 2003).

According to Figure 3, during the period of compression, the reactivation of basement faults has caused left-lateral strike-slip fault movement along NW-SE trends. This major NW-SE trending strike slip faults associated with narrow anticlinal ridges form positive flower structures. The NW-SE trending narrow faulted anticlinal zones with intense deformation separated by broad synclinal areas are interpreted by Balaguru, Nichols & Halls (2003) as possibly a large contractional duplex related to left lateral strike-slip faulting and transpressional fault movement since the Early Pliocene. Transpressional movement since the late Pliocene has caused major structural inversion and uplift. Renewed extension during the Plio-Pleistocene caused sequences repetition and have widened and modified the original synclines (Balaguru et al., 2003).

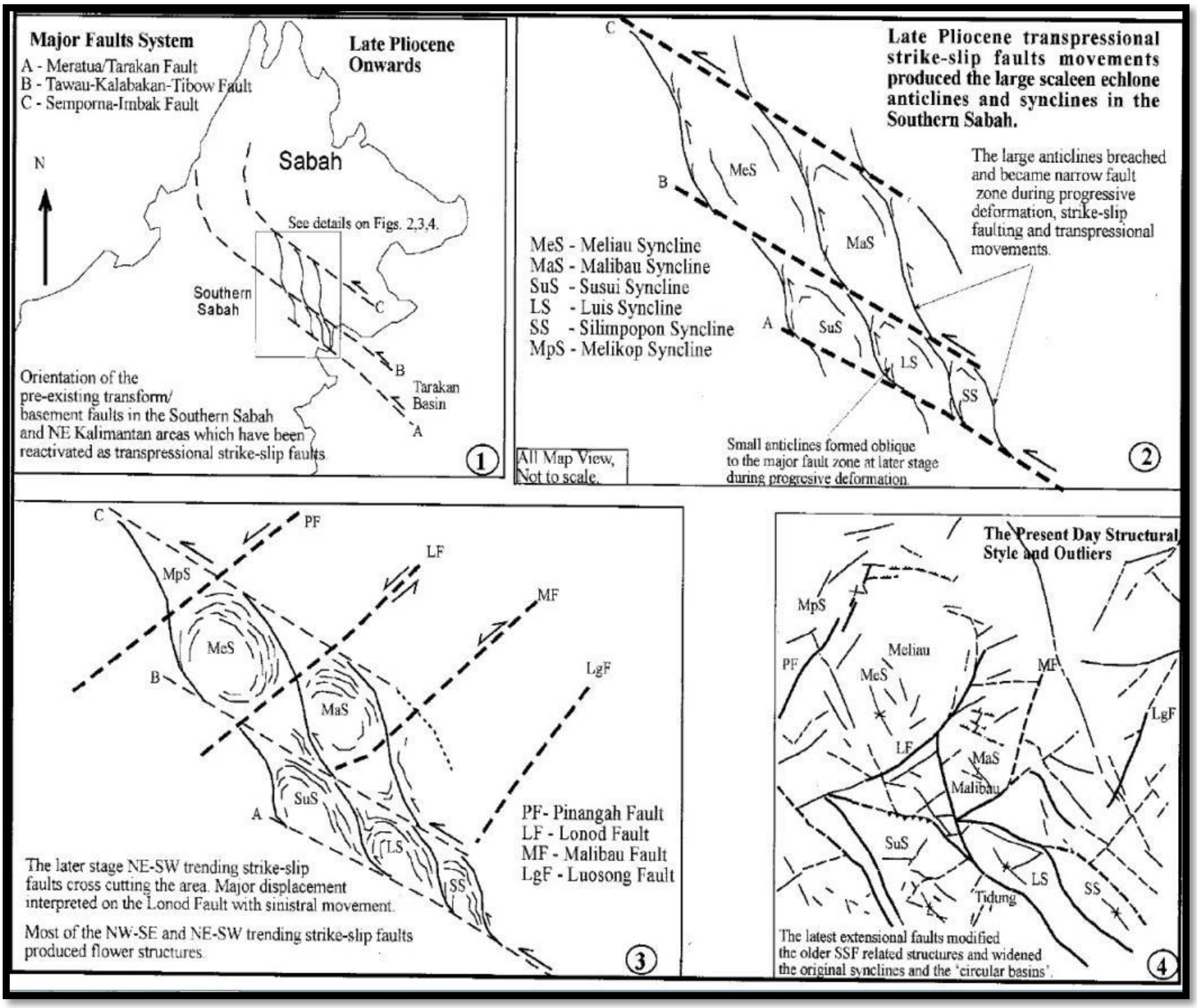


Figure 3: Proposed tectonic model of Southern Sabah showing the mechanism of development of 'Neogene' Circular basin based on (Balaguru et al., 2003).

CHAPTER 3

METHODOLOGY

Throughout the project several methods has been used in order to achieve the required objectives. The methodology that been used are like field mapping, sample collection, sample analysis and laboratory analysis.

3.1. Field Work and Geological Mapping

The main objective for field work is to do the geological mapping, observe the outcrops as well as to collect samples. A thorough planning need has been organized in order to manage samples and field data collection. Several equipment been used during the field trip such as the Bruntton compass, geological hammer, GPS and hand lens. Outcrops along the interest road have been given more focused to obtain necessary data.

3.2. Sample Collection and Petrography Analysis

Several rock samples have been collected from the outcrops for petrography analysis. Petrographic descriptions include details on mineral composition, sedimentary structures, texture, grain size and geological classification. Structural data also been collected to give ideas on deformation history of the study area.

3.3 Thin Section Analysis

In order to study the petrographic of the rock, rock samples are made into thin sections. The thin section analysis is a 0.03 mm thick slice of the rock sample that been used to view the microscopic image of the rock. With the aid of polarized microscope, the microscopic image of the rock can be seen clearly and its characteristics can be well defined to give insight on the sedimentology of the area.

3.4 Digital Elevation Model (DEM)

In order to look at the structure of the topography and the geomorphology of the project area, Digital Elevation Model (DEM) data will be used. To search for potential outcrops and to understand the general geology of the area, geological map will be used. Then, to make an updated map based on own interpretations, this geological map will be overlain on top of the DEM data map.

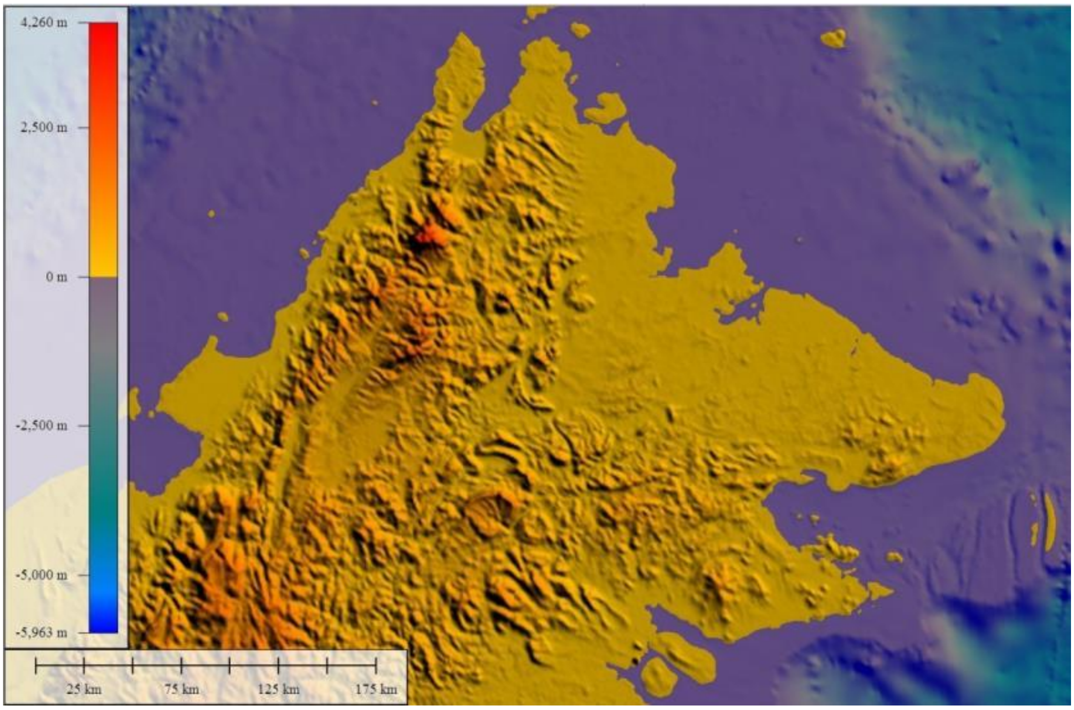


Figure 4 : DEM of Sabah using the Global Mapper software

3.5 Analysis of Several Previous Papers and Journals

To give better understanding of the geological history and stratigraphy of Sabah, there are several previous journals and papers been used as the source of references. My supervisor, Miss Sara Izzati has helped me a lot in providing some reliable papers from authors such as Robert Hall, Gary Nichols and Allagu Ballaguru. These papers has also provided me the required source of facts and information based on several previous conducted research which has given me some ideas on how to conduct my FYP.

3.6 Rose Diagram

Strike and dip data has been collected during the field trip using the Brenton compass. The adequate amounts of data were then used to construct the rose diagram. It is actually the frequency of lineament orientation that is being plotted. Throughout interpretation of the rose diagram, the direction of forces and mode of structure affecting the structure will be determined precisely.

Methodology (General Workflow)

LITERATURE REVIEW

- Sharing and discussion session with FYP supervisor
- Analysis of the Sabah related journals, research papers, articles and books
- Maps (DEM data, geological map)

FIELD TRIP

- Flight from KLIA to Tawau
- A week and a half filed trip in collaboration with Universiti Malaysia Sabah personnel and students to the target area
- Collect samples of the Neogene formation specifically Kapilit and Kalabakan formation samples
- Sketch and photograph some image of the outcrops
- Gather important data (strike, dip, coordinate, elevation)
- Tools required- Bruntton compass, Garmin GPS, geological hammerm, hand lens, digital camera.

LABORATORY ANALYSIS

- Sample preparation (thin sections and core plugs)
- Mineralogy and petrography studies using the microscope

INTERPRETATION

- Road Map
- Depositional environment
- Lineament Analysis
- Rose Diagram

CHAPTER 4

RESULTS & DISCUSSION

4.1 Synthetic Cross Section Map

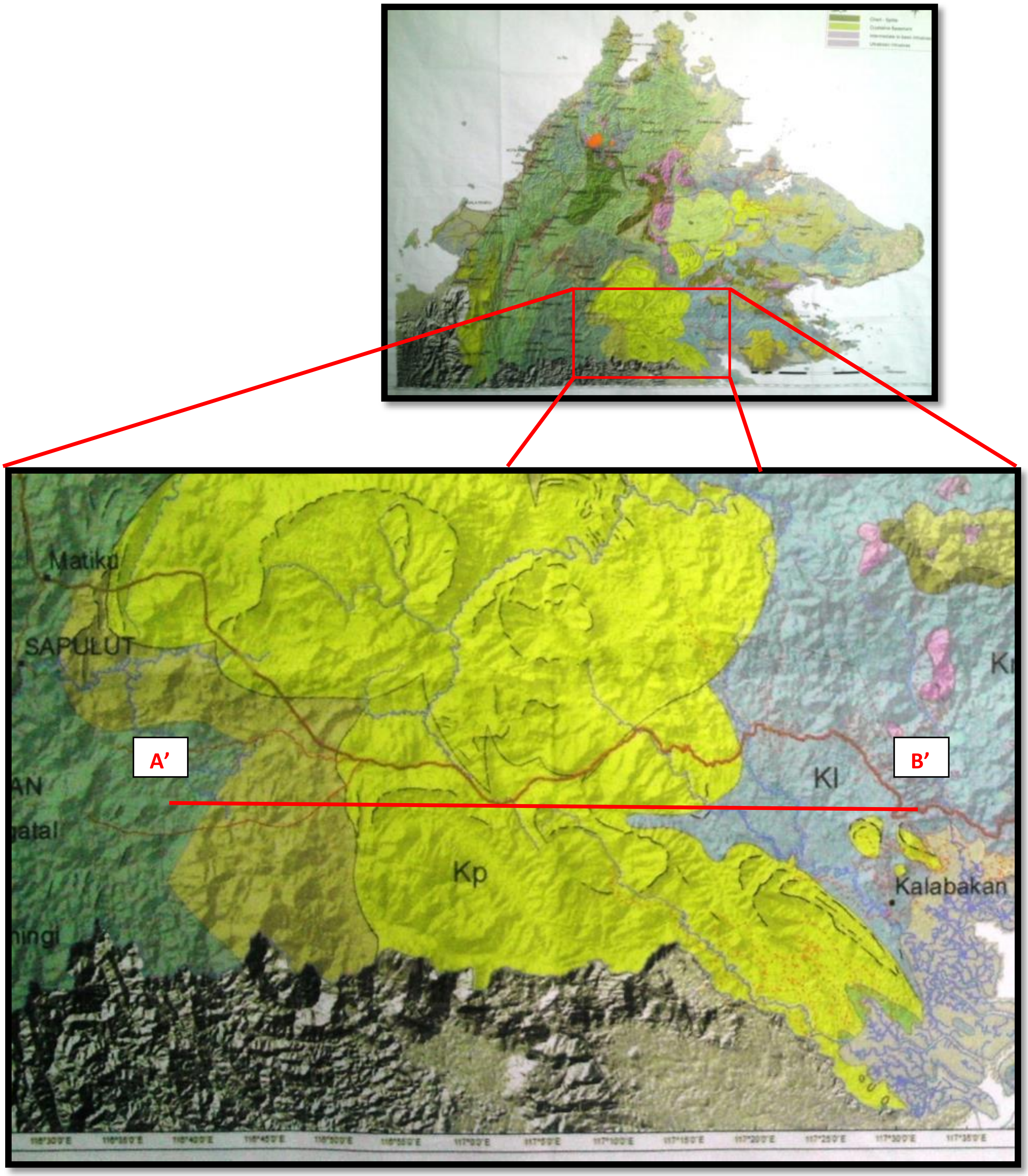


Figure 5: Morphostructural Map of South Sabah

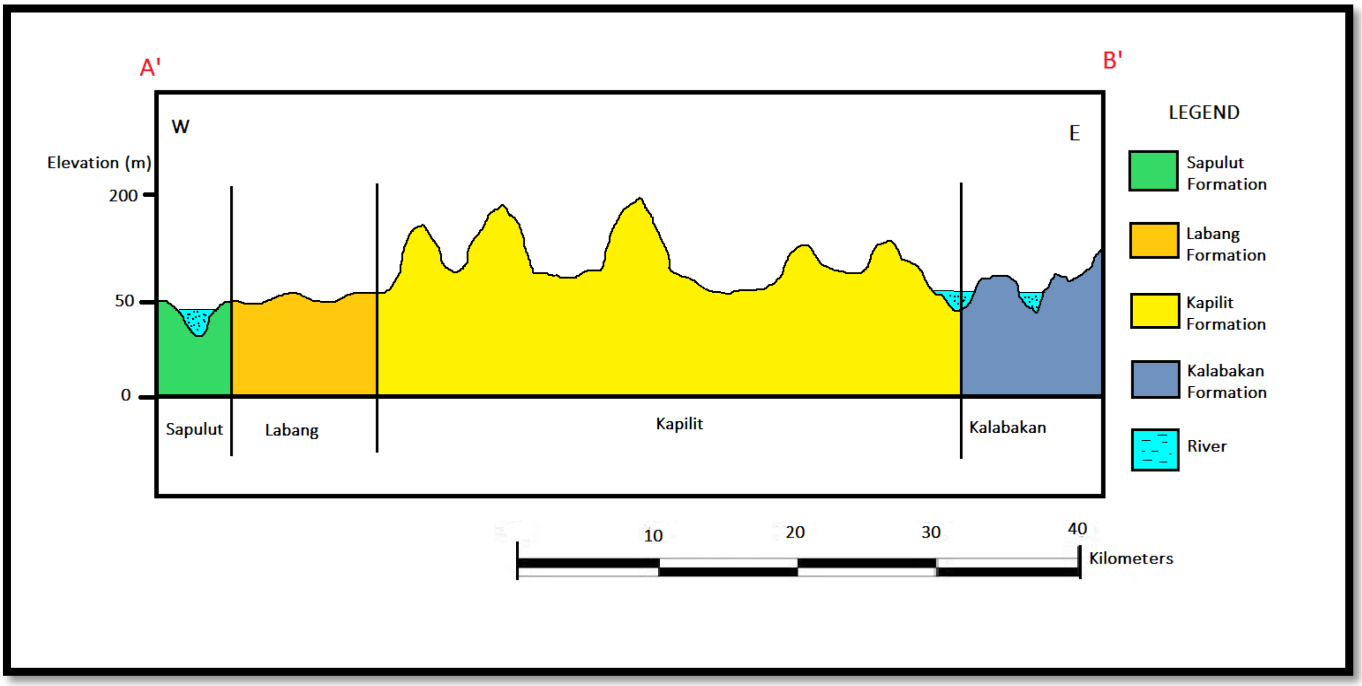


Figure 6: Synthetic Cross Section of line A' to B' of South Sabah

Figure 6 and 7 above shows the synthetic cross section of line A' to B' which covers the study area of the project which is Kapilit and Kalabakan formation in South Sabah. The field trips to Sabah have been conducted from 12th to 21st June 2014 accompanied by FYP and UTP supervisor Miss Nor Sara Izzatti.

4.2 Road Traverse Map

Field trip to Sabah was taken place from 12th to 18th May 2014. During the field trip, road traverse was conducted beginning at Kalabakan area at (N 4° 31' 23.9", E 117° 34' 02.0") and endpoint at Kapilit area formation (N 4° 30' 59.9", E 117° 14' 45.2"). The total length of the road traverse is around 68 KM. There are 8 localities or stop point during the whole process where detailed investigation of each outcrop was conducted whenever a reliable and good outcrop was seen during the traverse. There are 5 outcrops for Kalabakan formation and 3 outcrops for Kapilit formation. Strike and dip was measured for each outcrop using the Bruntton compass. Several samples were also collected for each outcrop for further studies where most of them are Sandstone and Siltstone.

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
1ST Locality	N 4° 31' 23.9"	E 117° 34' 02.0"	4.523306, 117.567222	55 m
2nd Locality	N 4° 31' 32.7"	E 117° 32' 41.5"	4.52575, 117.544861	78 m
3rd Locality	N 4° 31' 26.2"	E 117° 32' 23.0"	4.523944, 117.539722	84 m
4th Locality	N 4° 31' 39.4"	E 117° 31' 59.7"	4.527611, 117.53325	105 m
5th Locality	N 4° 31' 39.4"	E 117° 30' 58.1"	4.527611, 117.516139	189 m
6th Locality	N 4° 28' 2.50"	E 117° 22' 44.9"	4.467361, 117.379139	96 m
7th Locality	N 4° 30' 25.6"	E 117° 17' 12.6"	4.507111, 117.286833	63 m
8th Locality	N 4° 30' 59.9"	E 117° 14' 45.2"	4.516639, 117.245889	120 m

Table above: Table of coordinates of outcrop locality

Overall Road Traverse Map

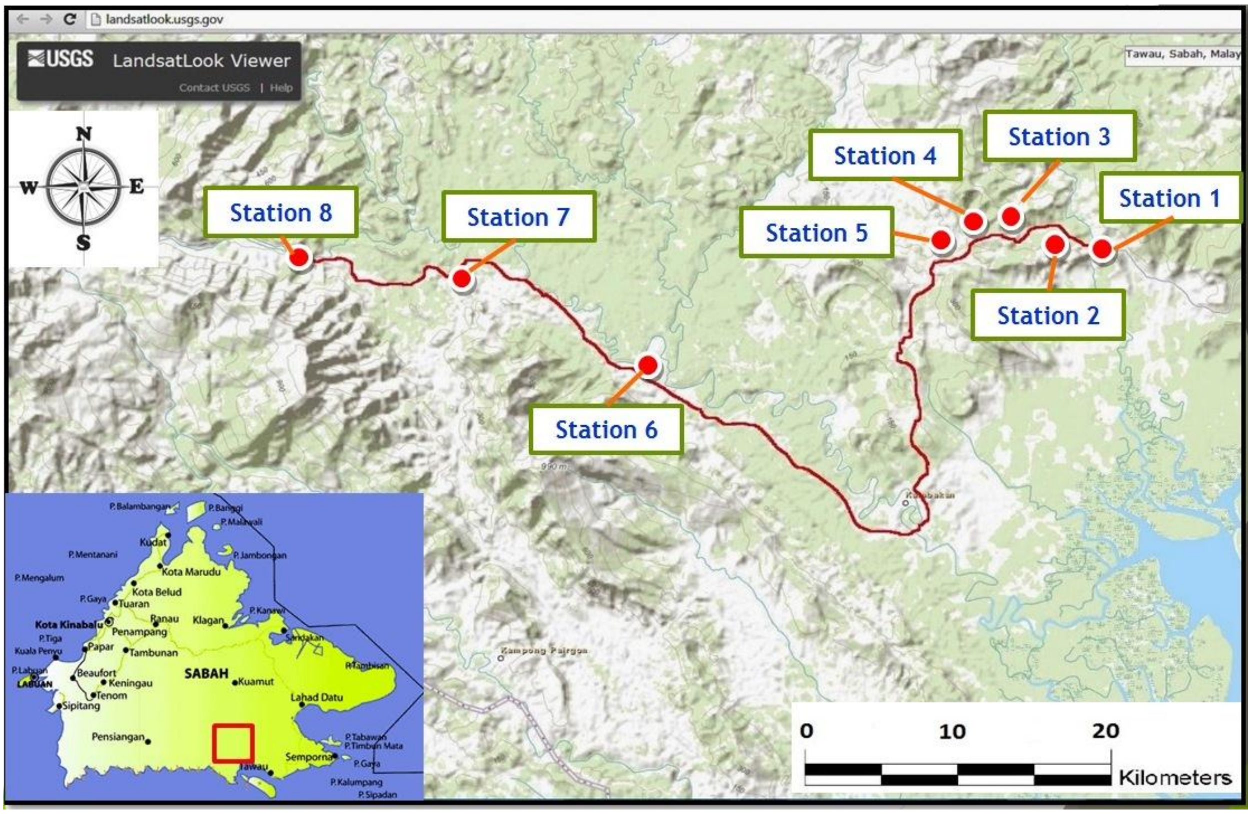


Figure 7: Road covered with 8 localities from Start point in Kalabakan formation to Endpoint in Kapilit formation (generated by USGS LandsatLook Viewer)

Litho Map of Study Area

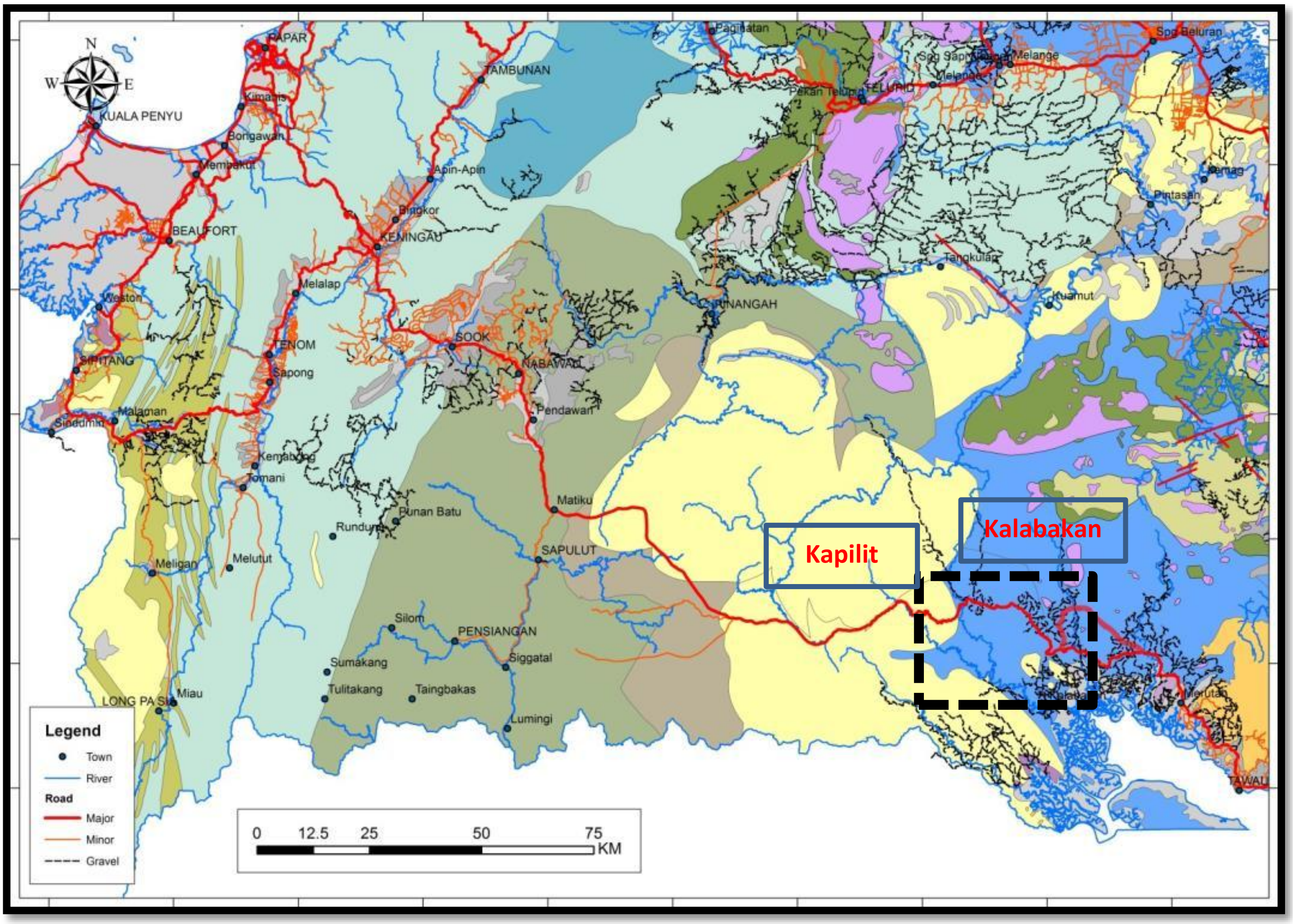


Figure 8: Litho map that show the area of interest

4.3 Lineament Anallysis

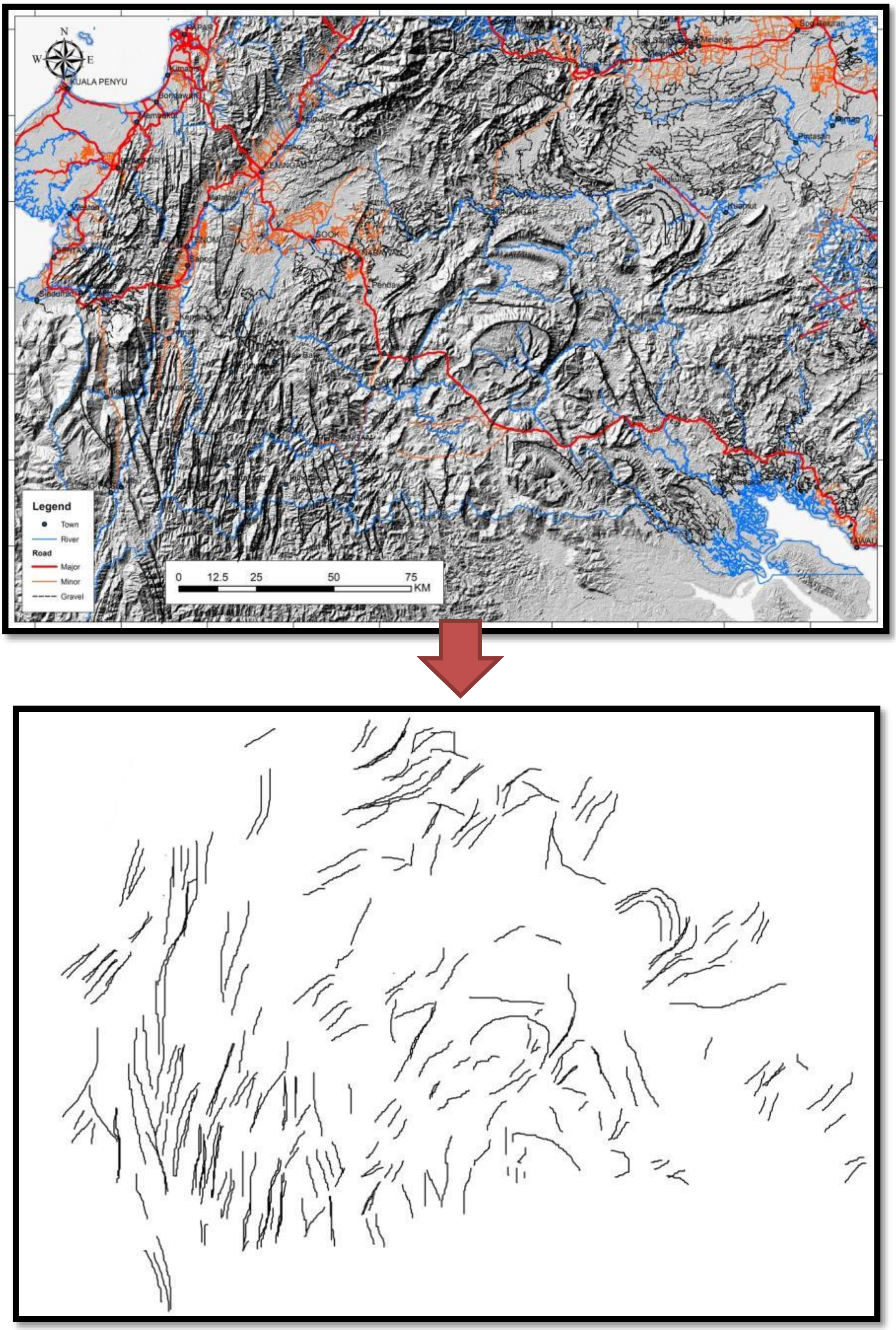


Figure 9: Lineament map produced using the Topographic map

A lineament is a linear feature in a landscape which is an expression of an underlying geological structure such as a fault. Typically a lineament comprise of a fault-aligned valley, a series of fault or fold-aligned hills, a straight coastline or indeed a combination of these features. Fracture zones, shear zones and igneous intrusions such as dykes can also give rise to lineaments.

Figure 8 shows the lineaments map managed to be interpreted which includes Kapilit and Kalabakan formation. Lineaments are often apparent in geological or topographic maps and can appear obvious on aerial or satellite photographs. Other definition of lineaments is as defined by Oxford Dictionary as a linear topographic feature of regional extent that is believed to reflect underlying crustal structure.

The term 'megalineament' has been used to describe such features on a continental scale. The trace of the San Andreas Fault might be considered an example. The Trans Brazilian Lineament and theTrans-Saharan Belt, taken together, form perhaps the longest coherent shear zone on the Earth, extending for about 4,000 km

The distinct features of lineament analysis in Figure 9 is that we can see through the semi-rounded shape of the famous Meliau Basin located in Central Sabah which sometimes geologist referred to as the ‘Circular Basin’. Station by station analysis in the next chapter will further be relate to this lineament analysis as most of the lineaments are majorly trending towards North East- South West direction.

4.4 Stop by Stop Analysis

1st Locality (Kalabakan)

Figure 10: 1st Outcrop Locality in overall map

Figure 10.1: Zoom in picture of 1st Outcrop Locality in overall map

Locality 1

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION ABOVE SEA LEVEL
1ST Locality	N 4° 31' 23.9"	E 117° 34' 02.0"	4.523306, 117.567222	55 m

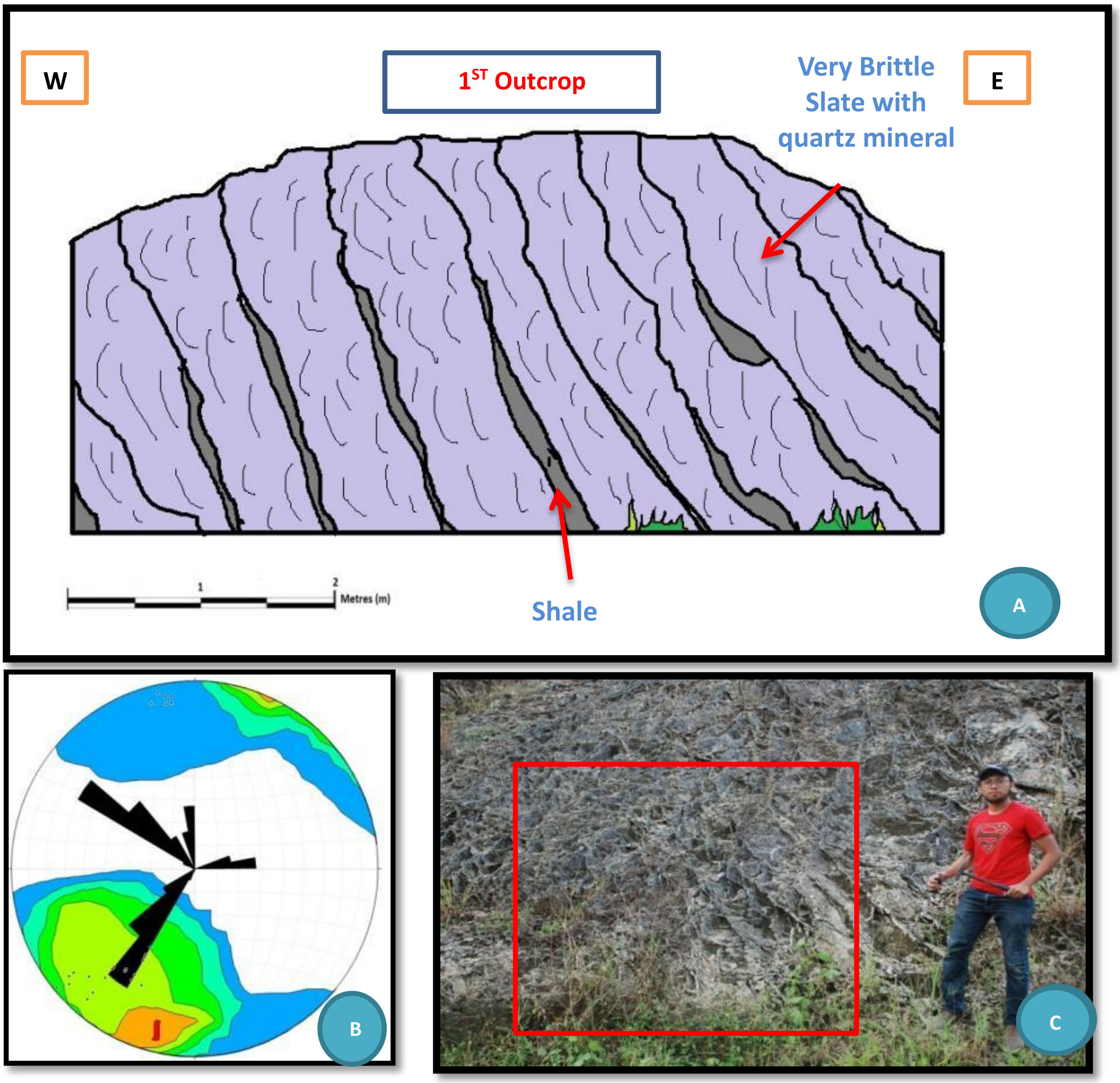


Figure 10a: Sketch of the Outcrop; Figure10b- Stereonet of Bedding; Figure 10c- The 1st Stop Outcrop

Based on the sketch picture of Outcrop 1, the outcrop is composed of shale interbedded with very brittle slate with quartz mineral. The younging direction is from the Left to the Right of the image. Due to high compaction pressure and high organic matter content, the shale has transformed into slate.

Slate is caused by strong compression causing fine grained clay flakes to regrow in planes perpendicular to the compression. Usually the compression is caused by very high plate tectonic movement. From the image, we can see that the compression comes from North East South West Direction.

Stereonet is represented by the bedding data gathered during the field trip. The strike is trending towards the North West- South East Direction whereas the dip is trending towards the North- East South West direction.

<u>Other Geological features appeared in Outcrop 1</u>

Figure 10d: Melanges boulder

A melange is formed in the accretionary wedge as sediment and oceanic crust is scraped off the descending plate in a subduction zone. The melange comprises a strongly brecciated unit with large blocks of pre-existing rocks in a deformed fine grained matrix. This melange boulder is actually consists of a jumble of large blocks of varied lithology sand is supported and separated by a matrix of fine grained material (shale or slate), with a tectonic fabric. Mélanges originate either as components of tectonic accretionary prisms, as a result of gravitational submarine sliding (olistostromes).

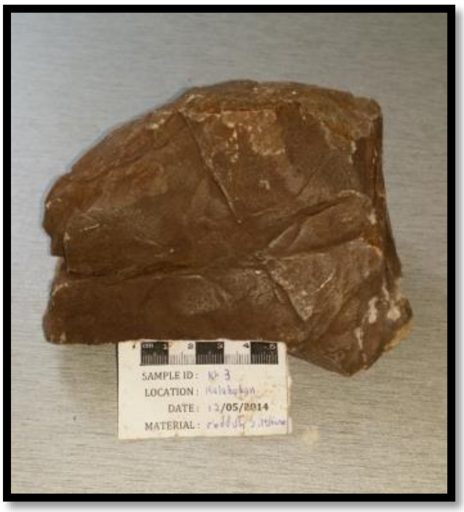
Figure 10e: Phacoid sandstone block

Because of its non-continuous characteristics, this phacoid shape sandstone block is considered to be one of melanges block unit in the 1st Outcrop area. It is a boulder which the inclusion of fragments of rock of all sizes, contained in a fine-grained deformed matrix

<u>Other Samples collected from Locality 1 (Kalabakan)</u>

Kb1-Sandstone sample

Kb2- Siltstone sample



Kb3-Reddish Siltstone sample

Kb5- Shale sample

Kb4- Siltstone interbedded with Quartz

2nd Locality (Kalabakan)

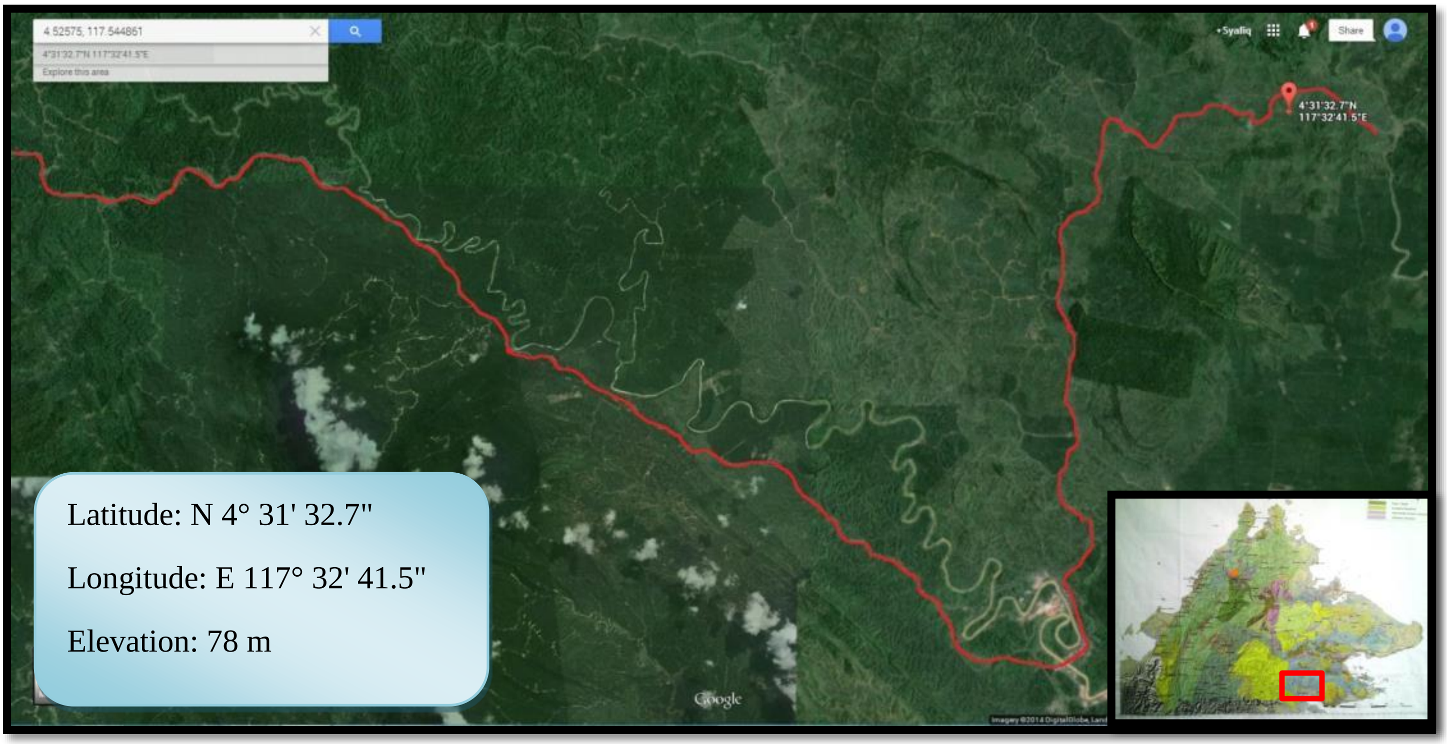


Figure 11: 2nd Outcrop Locality in overall map

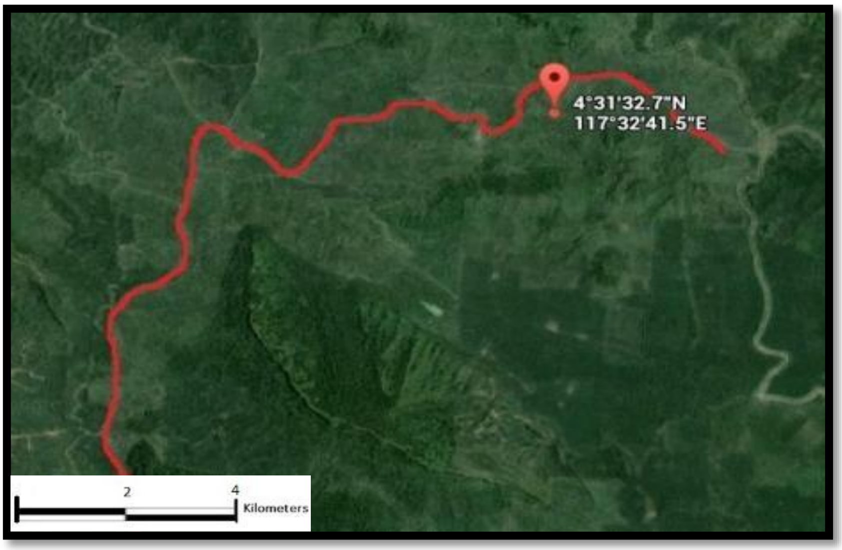


Figure 11: Zoom in picture of 2nd Outcrop Locality in overall map

Structural Analysis of Locality 2

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
2nd Locality	N 4° 31' 32.7"	E 117° 32' 41.5"	4.52575, 117.544861	78 m

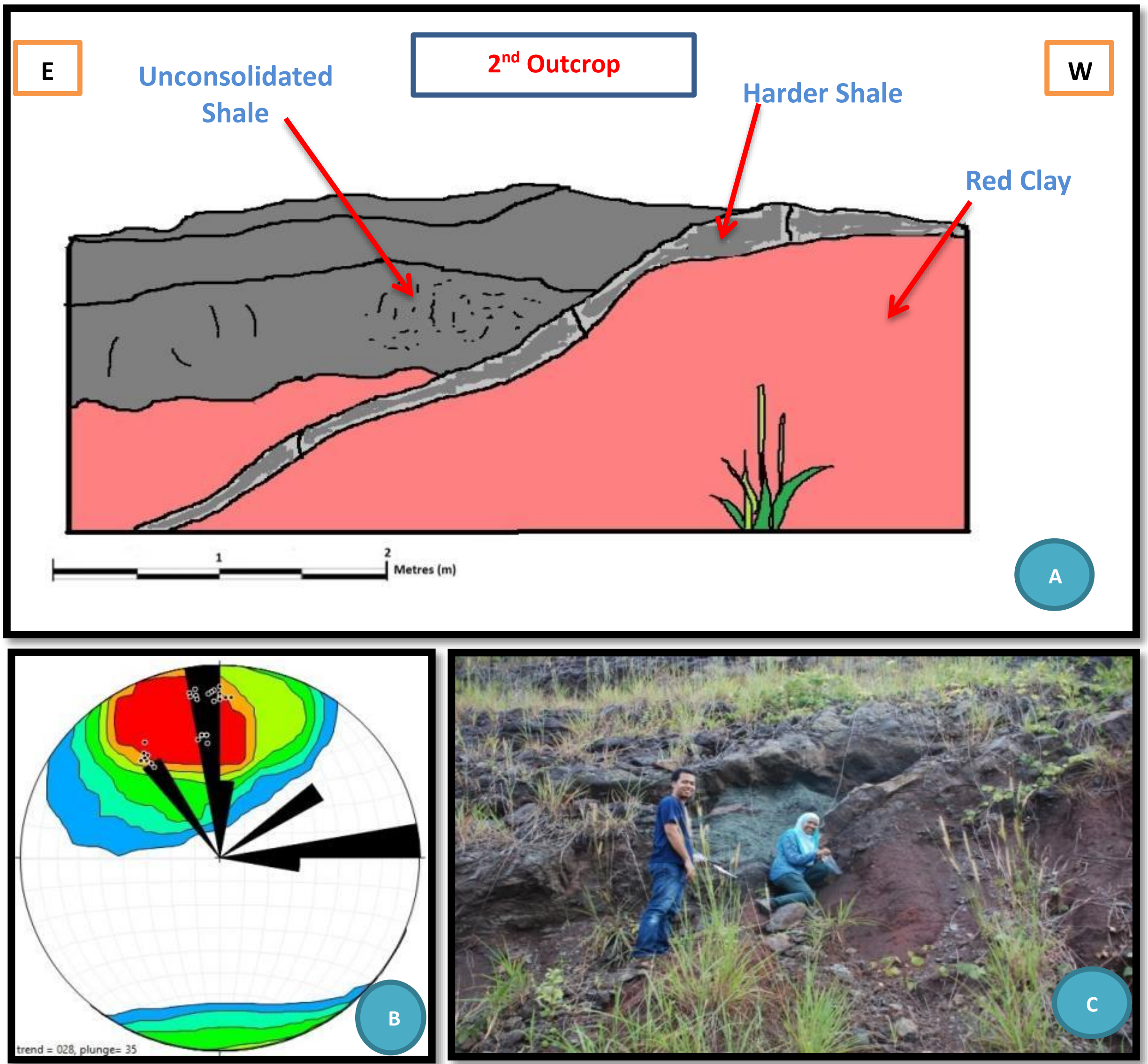


Figure 11a: Sketch of the Outcrop; Figure11b- Stereonet of Bedding; Figure 11c- The 2nd Stop Outcrop

Based on the sketch picture of Outcrop 2, the outcrop is composed of shale interbedded with red clay. Based on Law of Superposition, the red clay is considered to be the older rock compared to the shale. There are 2 kinds of shale in the outcrop which are the harder shale which in contact with the red clay and the other one is the unconsolidated shale.

The harder shale formed as a result of slight metamorphism with some pressure and temperature are applied on it. In contrast the unconsolidated shale is less metamorphosed as it is softer than the harder shale. The other theory is that, the harder shale is metamorphosed and uplifted first before the deposition of the unconsolidated shale.

The red coloured clay are as a result of iron leaching where it has high content of iron oxide (ferum oxide) in the clay.

The deposition environment of shale might be from deep marine or lagoon or any low energy environment. This is further clarified by the thin section analysis which shows that the grain sizes range from fine to very fine. This shows that the sediment is transported far from the source and deposited only when the energy is low.

The stereonet in Figure 11c represented by the bedding data gathered during the field trip. The strike is trending in West- East Direction whereas the dip is trending in North-South direction.

3rd Locality (Kalabakan)

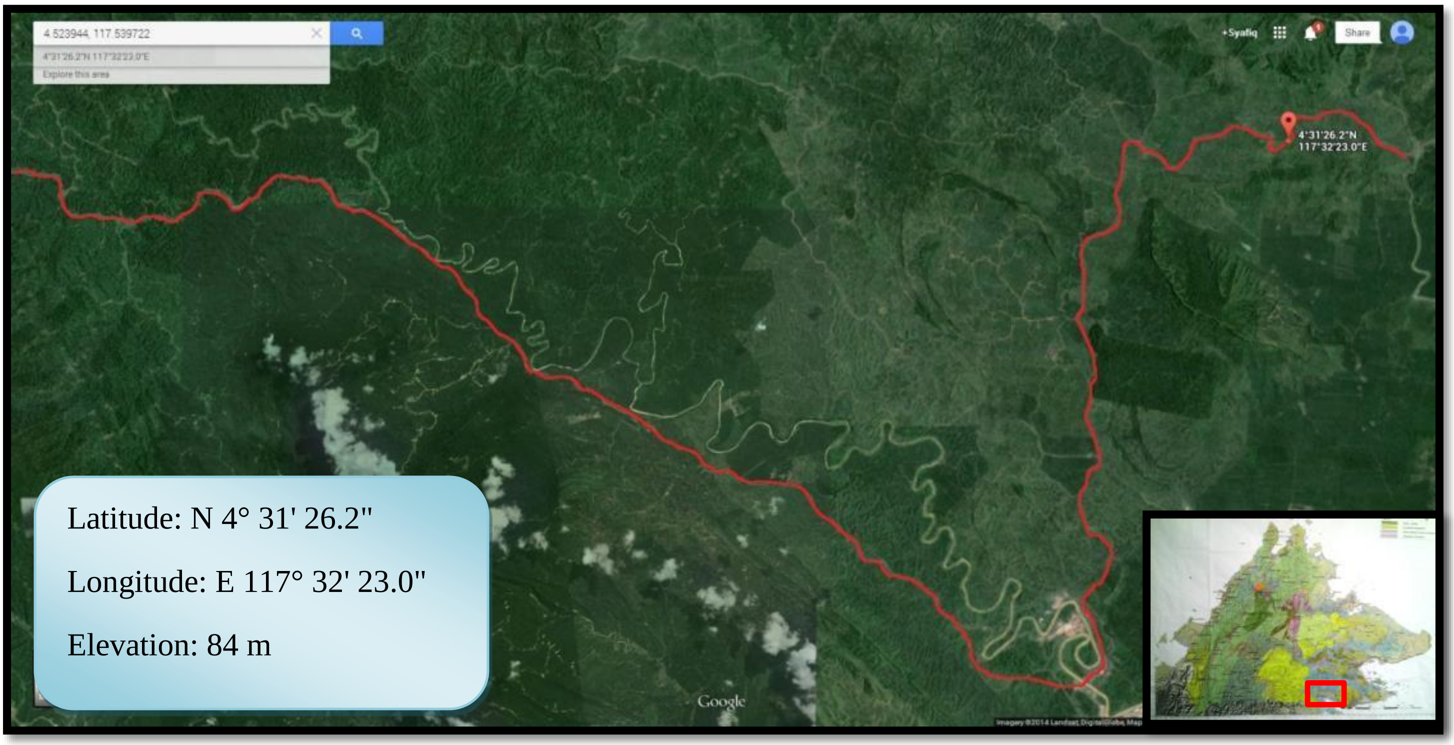


Figure 12: 3rd Outcrop Locality in overall map

Figure 12: Zoom in picture of 3rd Outcrop Locality in overall map

Structural Analysis of Locality 3

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
3rd Locality	N 4° 31' 26.2"	E 117° 32' 23.0"	4.523944, 117.539722	84 m

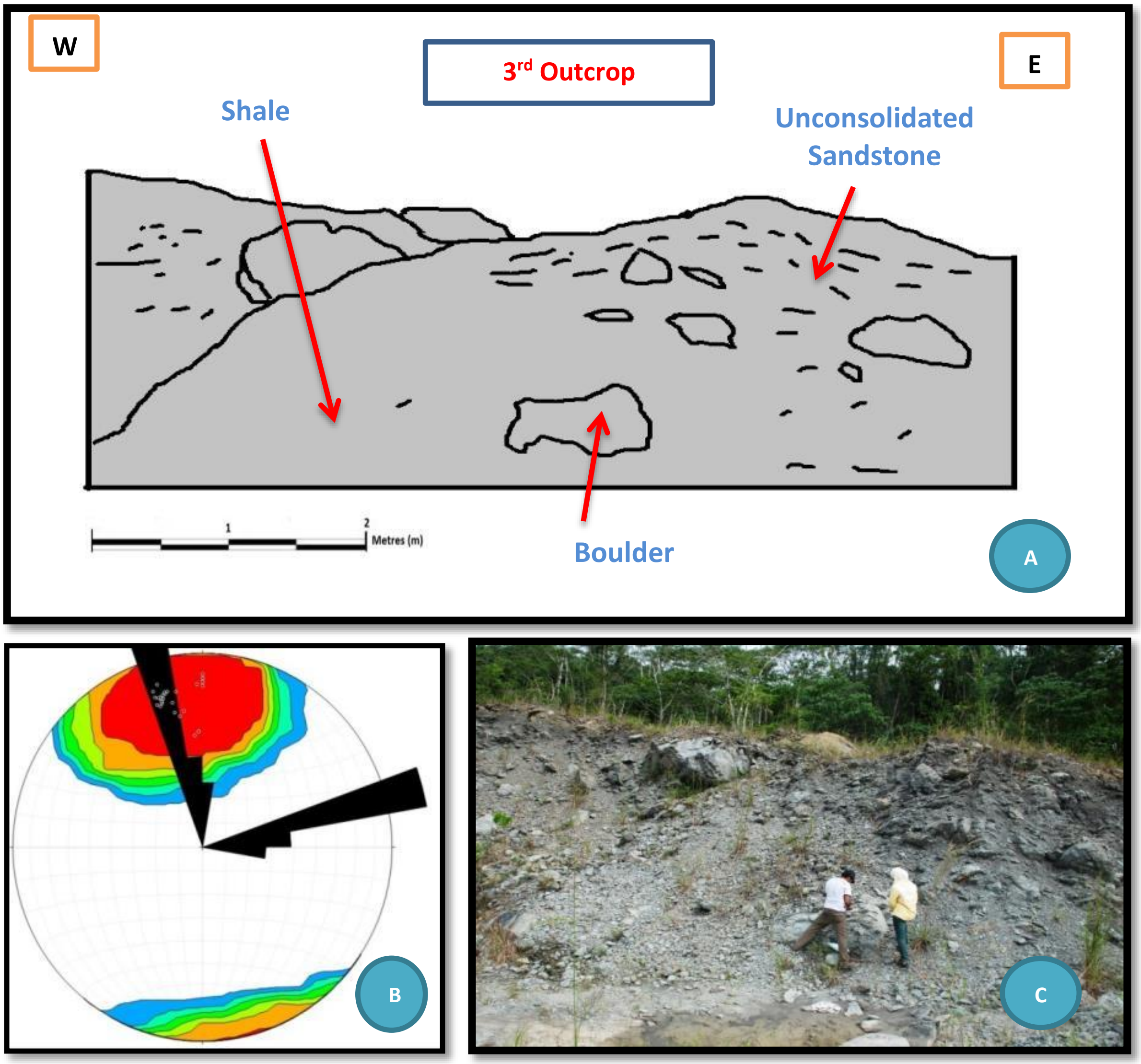


Figure 12a: Sketch of the Outcrop; Figure12b- Stereonet of Bedding; Figure 12c- The 3rd Stop Outcrop

Based on Figure 12 the main lithology of the outcrop is shale, unconsolidated sandstone and melanges boulder. The shale is believed to be deposited first followed by the unconsolidated sandstone. A catastrophic event probably hurricane or storms, then transported the melanges boulder to this area.

The grain size is utilised in understanding the deposition environment of the outcrop. The shale has a very fine-grained character compared to the unconsolidated sandstone which is fine grained. We can infer that the shale is transported far from the source compared to the unconsolidated sandstone. The probable environment of deposition might be from deep marine, distal plain or lagoon.

The stereonet in Figure 12c represented by the bedding data gathered during the field trip. The strike is trending in North East- South West Direction whereas the dip is trending in North West- South East direction. In comparison with the lineament analysis, this streonet has smiliar trending which conclude that the regional lineament is coherent with the outcrop scale.

<u>Sample collected from Locality 3</u>

Kb7-Sandstone sample

4th Locality (Kalabakan)

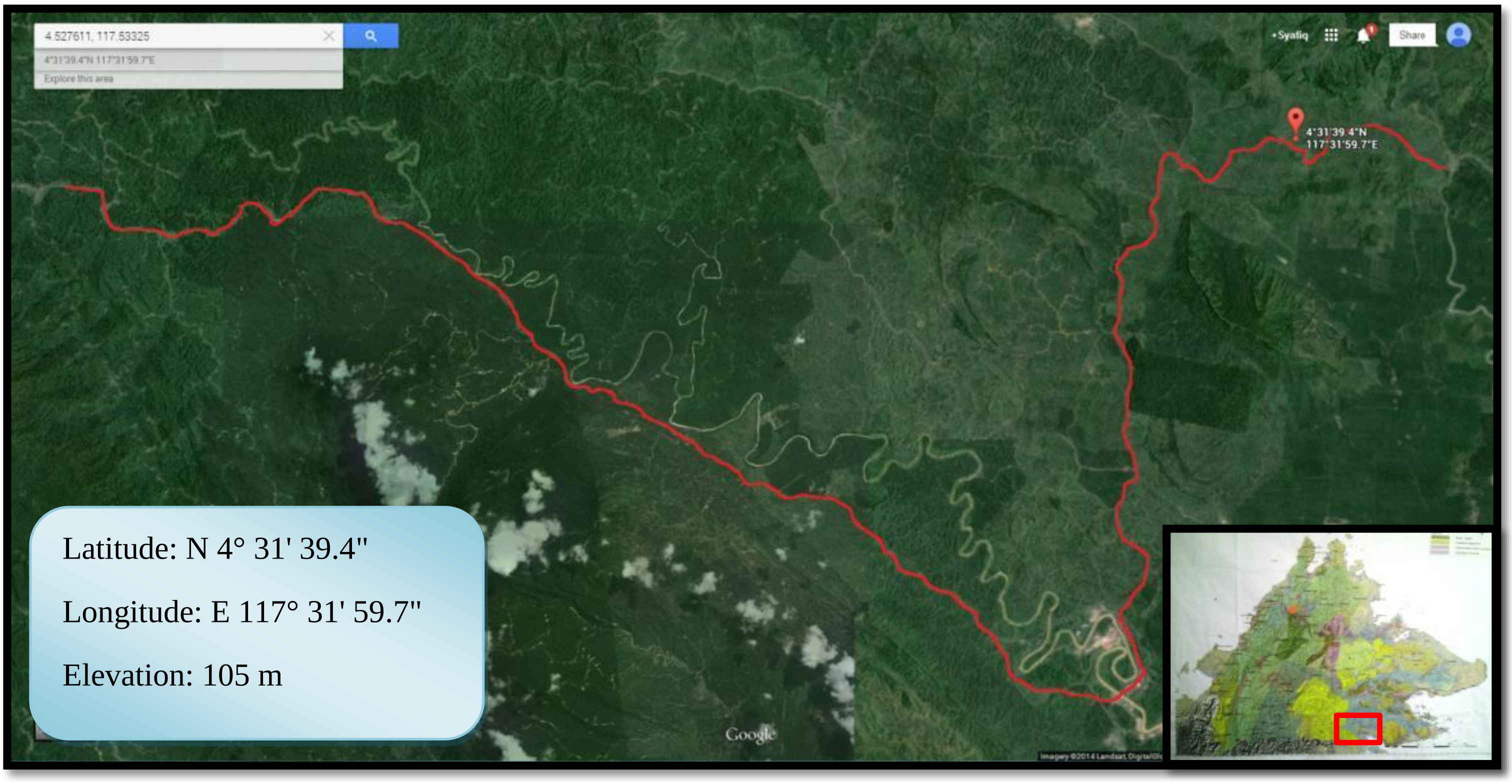


Figure 13: 4th Outcrop Locality in overall map

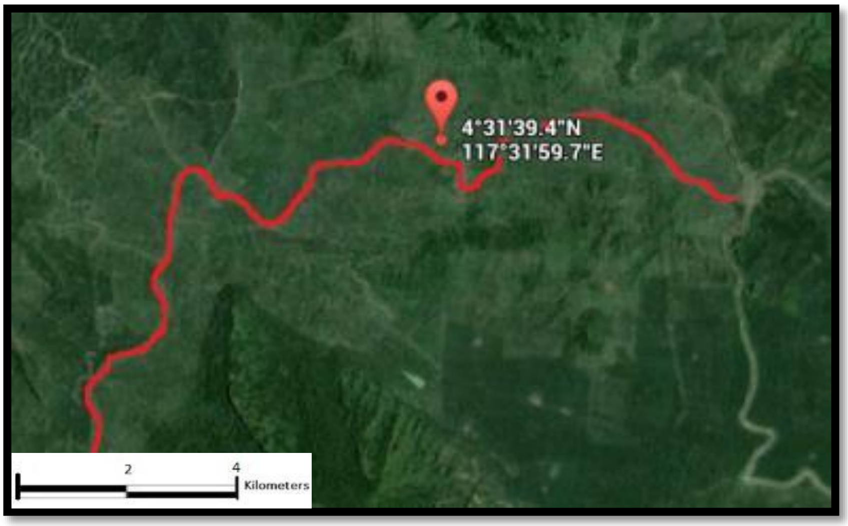


Figure 13: Zoom in picture of 4th Outcrop Locality in overall map

Structural Analysis of Locality 4

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
4th Locality	N 4° 31' 39.4"	E 117° 31' 59.7"	4.527611, 117.53325	105 m

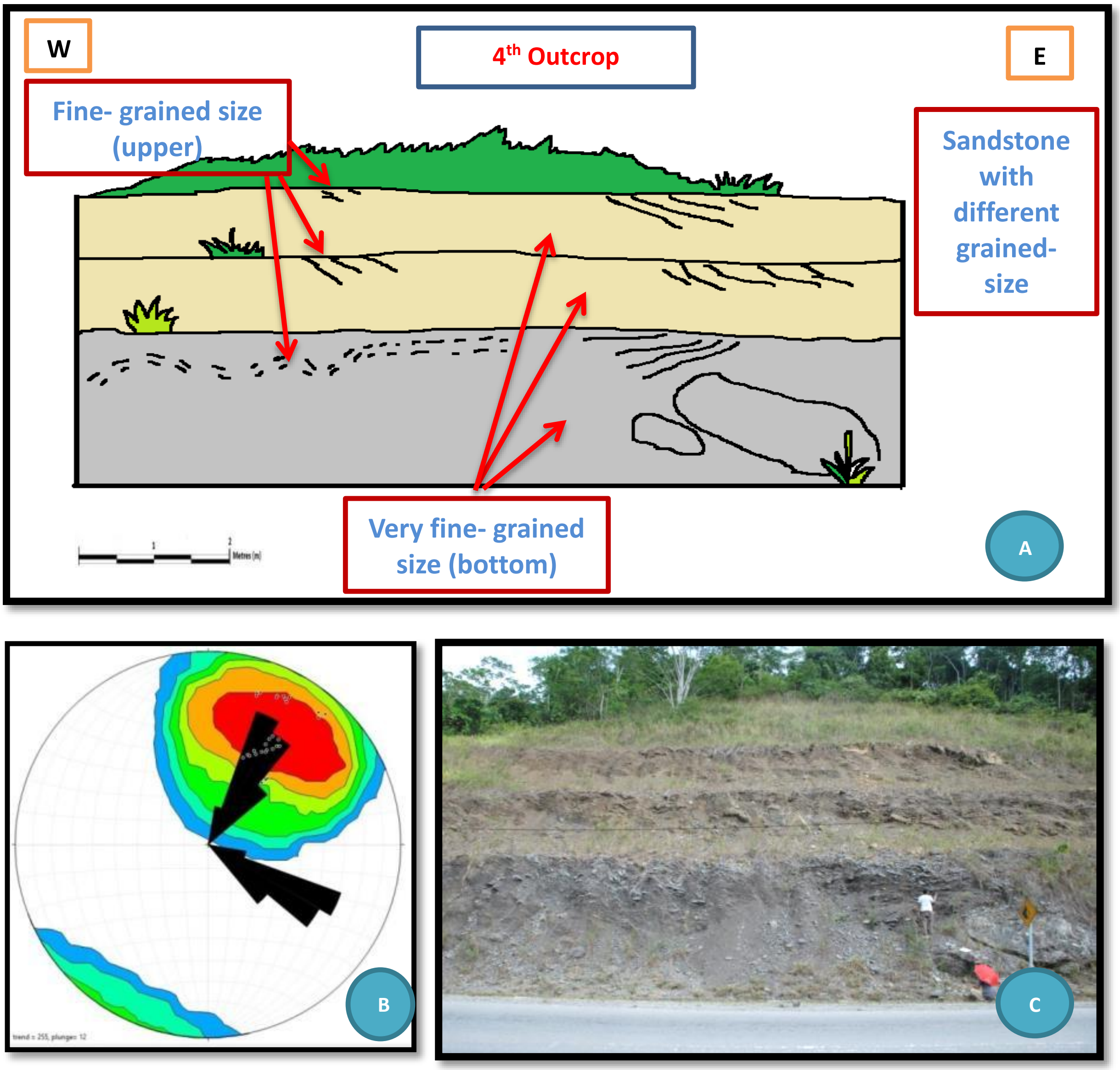


Figure 13a: Sketch of the Outcrop; Figure13b- Stereonet of Bedding; Figure 13c- The 4th Stop Outcrop

The main lithology of this Outcrop 4 is sandstone with different grain size. There are 3 distinct bedding of the outcrop where for each bedding, the bottom part of it is mainly very fine-grained sandstone while the upper part is fine grained sandstone.

In order to understand the deposition environment of the outcrop, we can see the grain size characteristics. The very fined-grained sandstone concludes that it is transported far from the origin of the source. While in comparison, the fine grained sandstone deposited from a less far distance from the origin.

The probable environment of deposition might also be from deep marine, distal plain or lagoon due to grain size character.

The stereonet in Figure 13c represented by the bedding data gathered during the field trip. The strike is trending in North West- South East Direction whereas the dip is trending in North East- South West direction. When compare with the lineament analysis, this stereonet has different trending which conclude that the regional lineament is non-coherent with the outcrop scale. These maybe happened due to the effect of wrench- fault occur in these area.

Figure 13d- Conjugate fracture at 4th outcrop

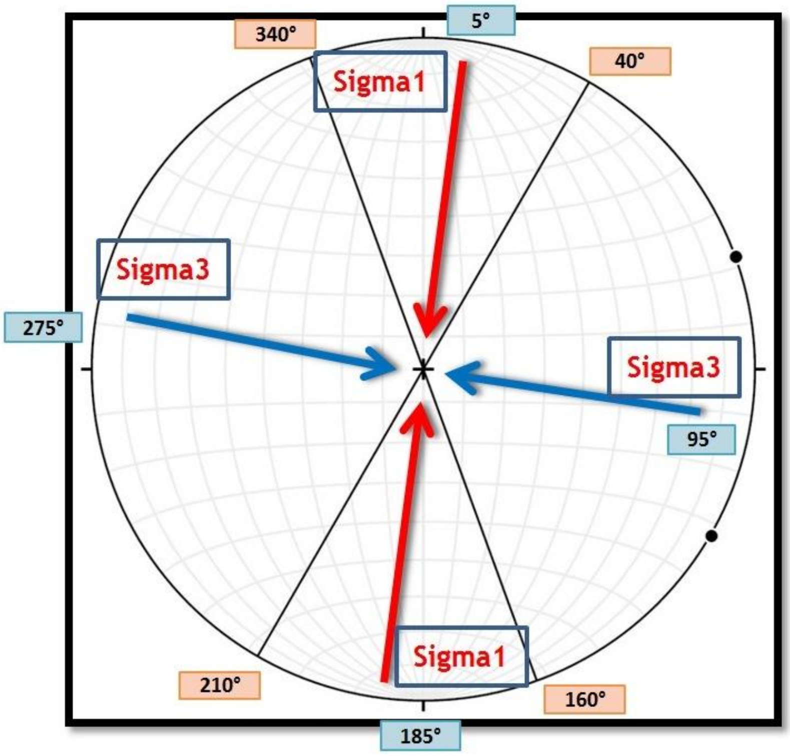


Figure 13e- Conjugate fracture rose diagram at 4th outcrop

The rose diagram has been used to analyse the fracture of conjugate fracture in outcrop 4 (Figure 13d). Based on the rose diagram (Figure 13e), the maximum stress, Sigma1, tend to trend in North East-South West (NE/SW) direction while the minimum stress Sigma 3 trending in North West-South East (NW/SE) direction. Fractures are commonly caused by stress exceeding the rock strength, causing the rock to lose cohesion along its weakest plane

<u>Sample collected from Locality 4</u>

Kb8-Shale sample

5th Locality (Kalabakan)

Figure 14: 5th Outcrop Locality in overall map

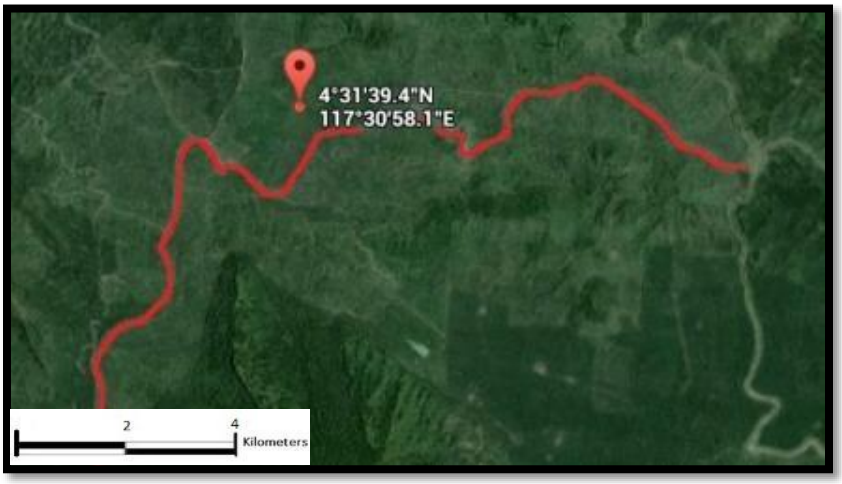


Figure 14: Zoom in picture of 5th Outcrop Locality in overall map

Structural Analysis of Locality 5

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
5th Locality	N 4° 31' 39.4"	E 117° 30' 58.1"	4.527611, 117.516139	189 m

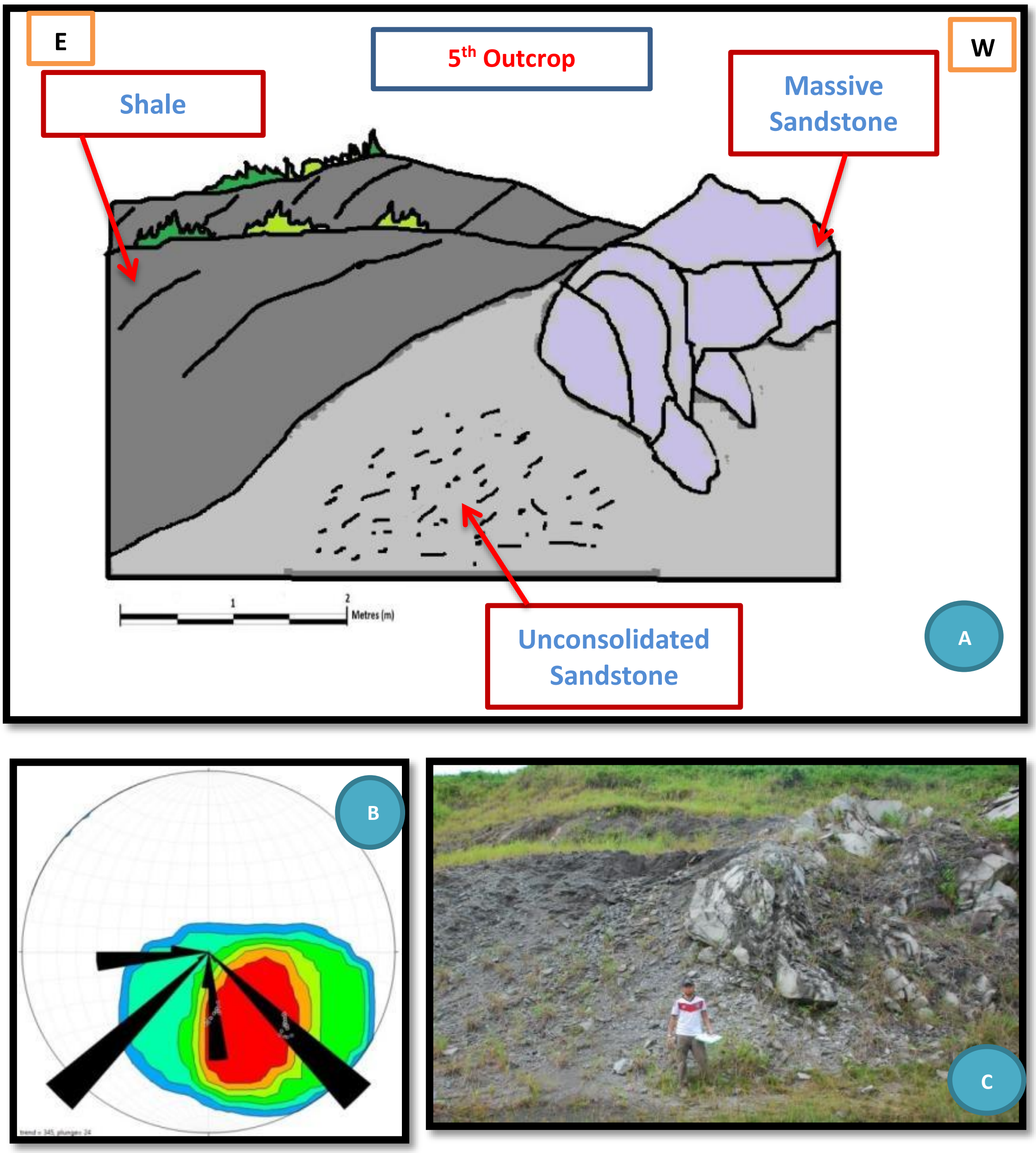


Figure 14a: Sketch of the Outcrop; Figure14b- Stereonet of Bedding; Figure 14c- The 5th Stop Outcrop

The 5th Outcrop lithology composed of unconsolidated sandstone, massive sandstone and shale. The unconsolidated sandstone is speculated to be deposited first before the deposition of the shale beds. The massive sandstone boulder might be transported by catastrophic event such as hurricane or storms.

In terms of grain size which varies from fine to very fine grained often regarded to have a low energy depositional environment. For instance, the deposition environment could be deep marine, lagoon or distal coastal plain.

The strike trend propagates rather towards North East- South West direction based in Figure 14b. When compare with the lineament analysis, this stereonet has same trending which conclude that the regional lineament is coherent with the outcrop scale.

Sample collected from Locality 5

Kb9-Massive sandstone sample

Figure 14d: Sedimentary structure of nodules at Outcrop 5

Based on Figure 14d, we can see the nodules formed as a sedimentary structure at Outcrop 5. Nodules are sometimes called as concretions where it commonly forms in sediments after deposition. Nodules can form at numerous times during diagenesis and burial however the majority of nodules form before the main phase of compaction which is during the early diagenesis. From Figure 14d we can deduced that the nodules is well preserved from compaction where the shale has undergone. Sometimes, we can found several kind of fossils in the nodules as it is well preserved from further compaction and high temperature.

6th Locality (Kapilit)

Figure 15: 6th Outcrop Locality in overall map

Figure 15: Zoom in picture of 6th Outcrop Locality in overall map

Structural Analysis of Locality 6

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
6th Locality	N 4° 28' 2.50"	E 117° 22' 44.9"	4.467361, 117.379139	96 m

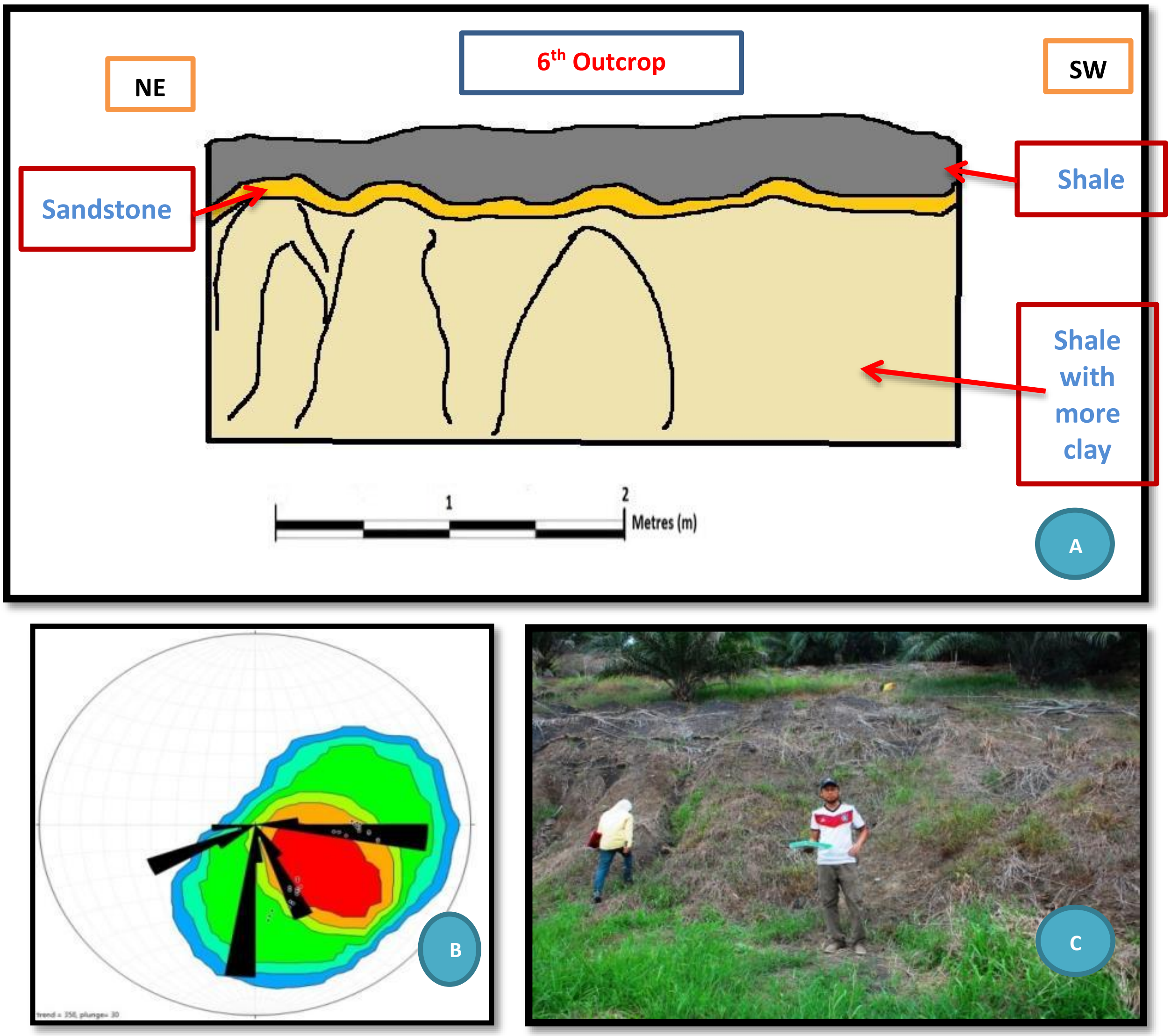


Figure 15a: Sketch of the Outcrop; Figure15b- Stereonet of Bedding; Figure 15c- The 6th Stop Outcrop

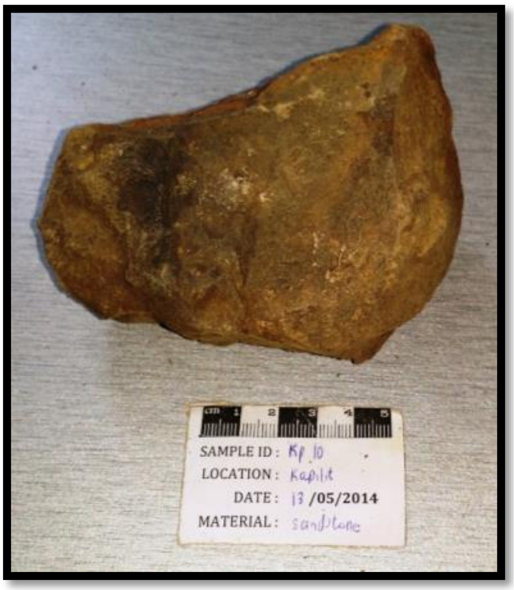
The 6th Outcrop is the first outcrop of Kapilit formation throughout the road traverse. This outcrop is mainly characterized by the interbedded shale, sandstone and shale with more clay as shown in Figure 15c. The shale with more clay is deposited first followed by thin layer of sandstone and then followed by shale.

Based on Figure 15d, we can see the load cast at the bottom of the thin sandstone at outrop 6. The load cast was deposited and formed at the bottom layer of the thin sandstone. Load cast are the sedimentary structure happened due to deposition of denser beds on a less dense hydroplastic layer. Muds, silts or finer sands are some of the examples of less dense hydroplastic layer while in contrast, the sands, coarse sands or gravels are the examples of the denser material. In geological history point of view, the less dense hydroplastic layer are formed first and considered to be older than the denser layer which is younger.

Figure 15d: Load cast at the bottom of the thin sandstone

The strike and dip trends of the outcrop can be seen through the stereonet in Figure 15b. Strike of the beds fairly trends towards the North-East South West Direction while the dip is trending North-West South East direction. The bedding of the strike does not follow the trend of the done earlier lineament analysis. This maybe happened due to the effect of the wrench faulting which maybe alter the strike of direction.

Sample collected from Locality 6



Kp10- Sandstone sample

7th Locality (Kapilit)

Figure 16: 7th Outcrop Locality in overall map

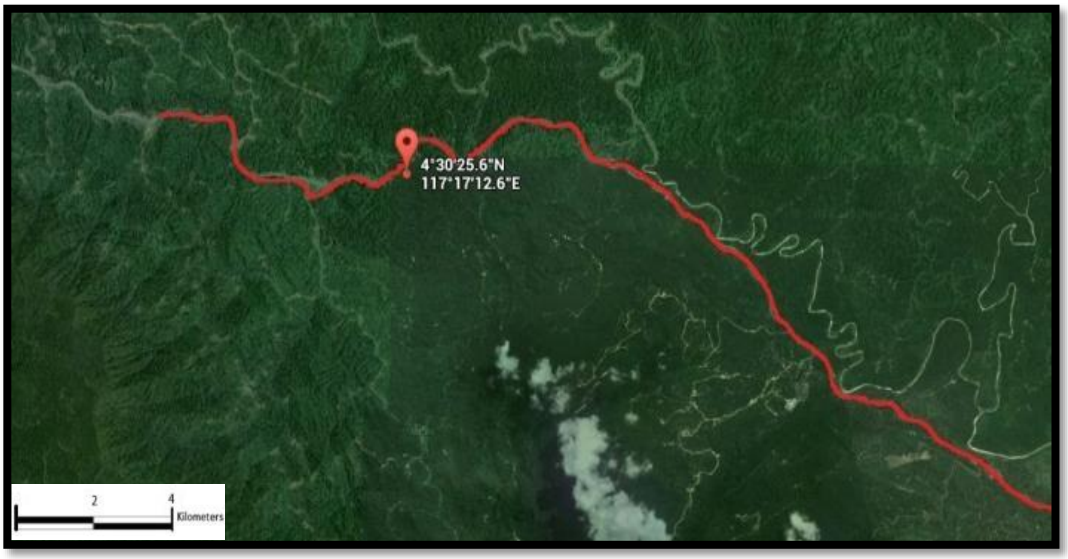


Figure 16: Zoom in picture of 7th Outcrop Locality in overall map

Structural Analysis of Locality 7

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
7th Locality	N 4° 30' 25.6"	E 117° 17' 12.6"	4.507111, 117.286833	63 m

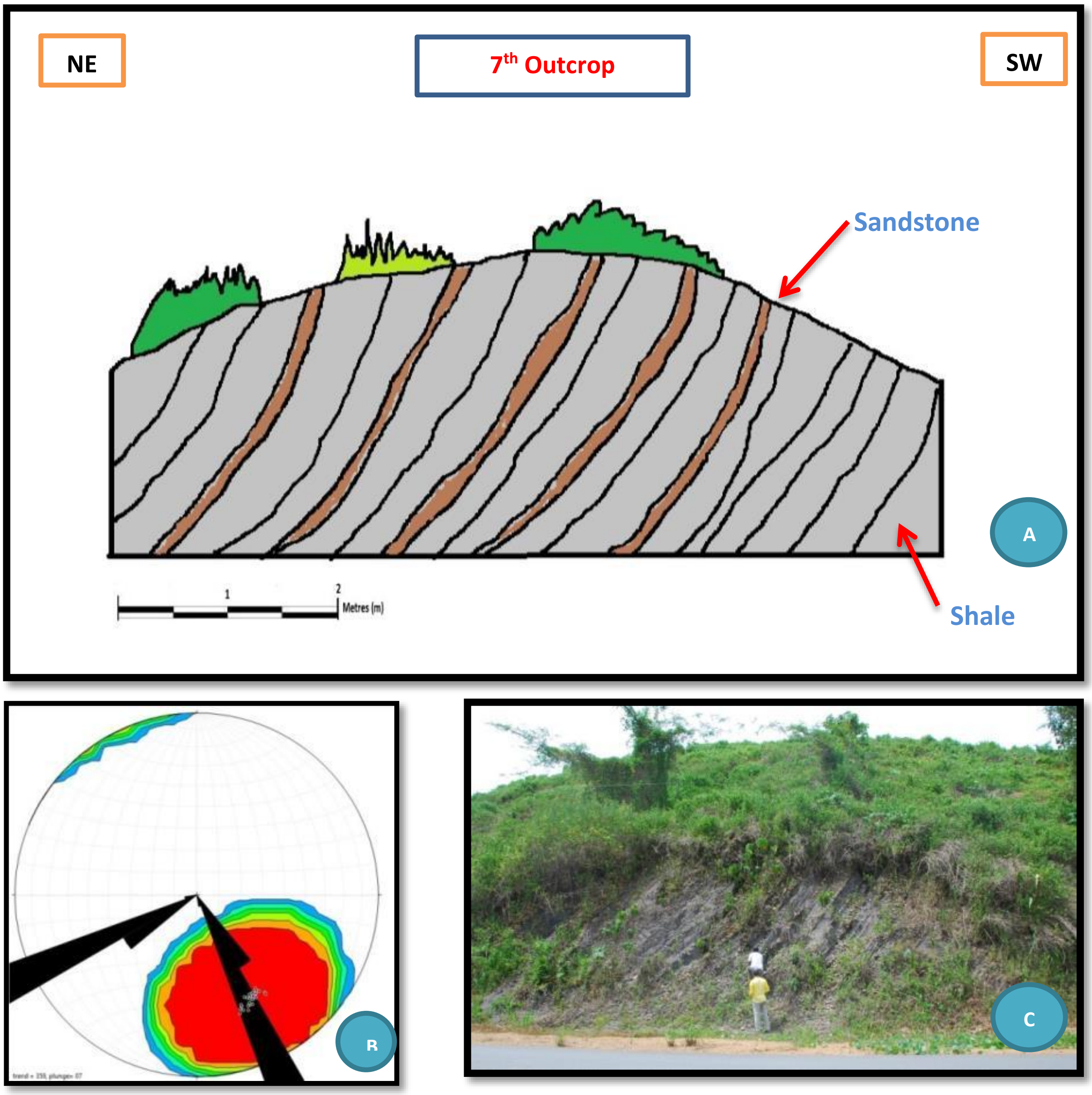


Figure 16a: Sketch of the Outcrop; Figure16b- Stereonet of Bedding; Figure 16c- The 7th Stop Outcrop

The 7th Outcrop is the second outcrop of Kapilit formation throughout the road traverse. This outcrop is mainly characterized by the alternating sequence of shale and thin layer of as shown in Figure 15c.

The presence of shale which indicates that it deposited in a low energy environment with sandstone has strong inference that it was deposited in a shallow marine environment which might be in distal coastal plain.

The strike and dip trends of the outcrop can be seen through the stereonet in Figure 16b. Strike of the beds fairly trends towards the North-East South West Direction while the dip is trending North-West South East direction. The bedding of the strike does not follow the trend of the done earlier lineament analysis. This maybe happened due to the effect of the wrench faulting which maybe alter the strike of direction.

Figure 16d: Imbrication at Outcrop 7

Based on Figure 16d, we can see imbrication formed on the surface. Imbrication is the orderly, overlapping arrangement of flattened or sub-spheroidal grains in the direction of flow. Imbrication is important for geologist to understand ancient current flow. Flow in this case is usually water flow, but it can also be other types of fluid flow. In this case the flow is from right to left of the image. Imbrication is also sometimes called shingling, as the particles line up overlapping like shingles.

<u>8th Locality (Kapilit)</u>

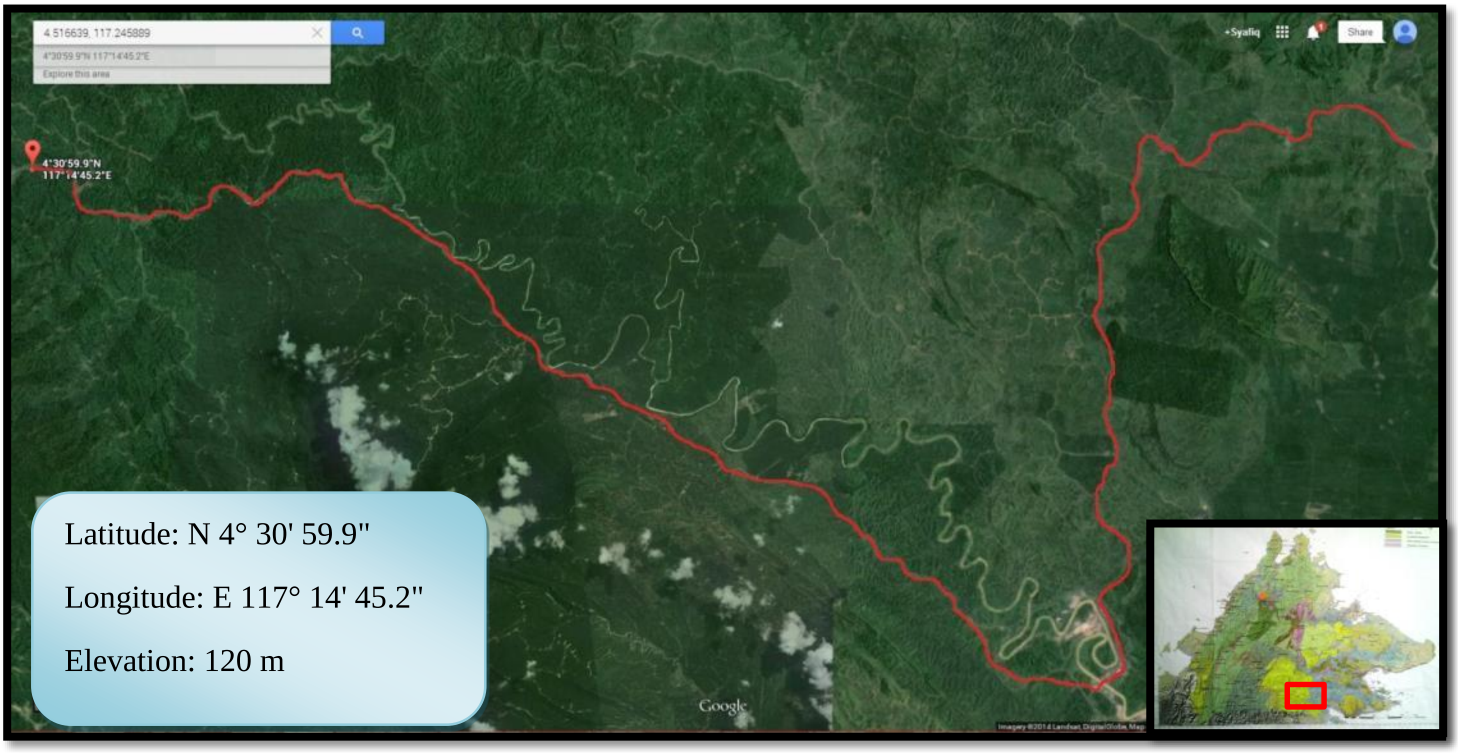


Figure 17: 8th Outcrop Locality in overall map

Figure 17: Zoom in picture of 8th Outcrop Locality in overall map

POSITION OF OUTCROP	LATITUDE	LONGITUDE	FORMATTED LTD/LGTD	ELEVATION
8th Locality	N 4° 30' 59.9"	E 117° 14' 45.2"	4.516639, 117.245889	120 m

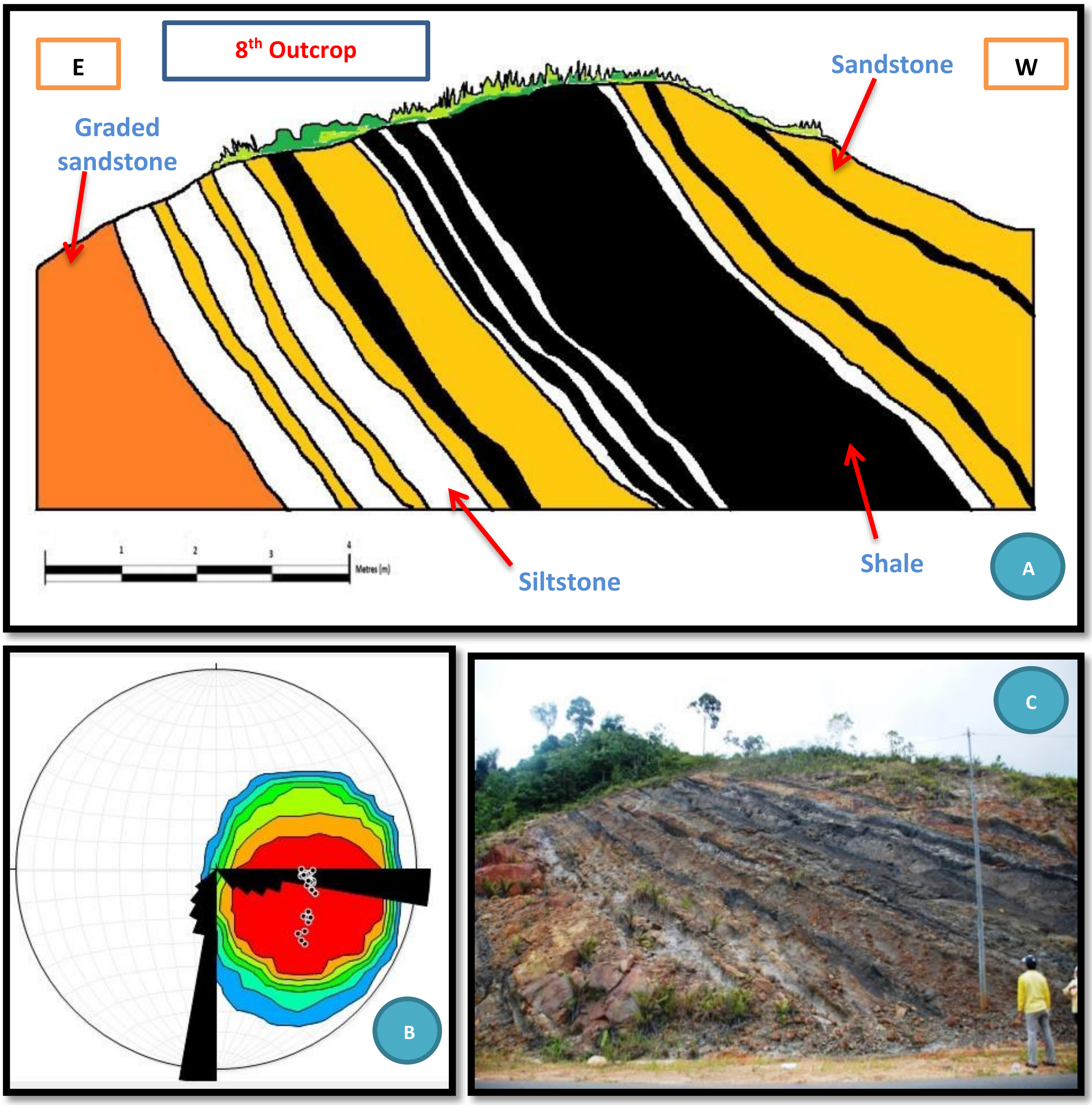


Figure 17a: Sketch of the Outcrop; Figure17b- Stereonet of Bedding; Figure 17c- The 8th Stop Outcrop

This 8^{th} outcrop is the last outcrop of the whole road traverse. The whole outcrop is approximately 20 metres in length. The younging direction is from the left of the image Figure 17c to the right. Graded sandstone is deposited first followed by alternating sequences of siltstones and sandstones and then finally shale.

Siltstone represents natural depositional environments transitional between those of shale and sandstone. For example, on the ocean floor clay dominates sediment deposition in the deep ocean far from shore, whereas sand is commonly deposited closer to shore in shallow water. Silt would therefore be deposited in between these two extremes, on the continental slope. Siltstone in this case, when found within a sequence of sedimentary rocks, often represents such a transitional environment.

Siltstone usually forms in marine, in quieter environments than the places that make sandstone. Yet there are still currents that carry off the finest clay-size particles. It's tempting to suppose that the fine lamination represents daily tidal surges.

The shale has a very fine-grained character compared to sandstone. We can infer that the shale is transported far from the source compared to the unconsolidated sandstone. The probable environment of deposition might be from deep marine, distal plain or lagoon.

The strike and dip trends of the outcrop can be seen through the stereonet in Figure 17b. Strike of the beds fairly trends towards the North- South direction while the dip is West - East direction. The bedding of the strike does not follow the trend of the done earlier lineament analysis. This may happened due to the effect of the wrench faulting which may alter the strike of bedding direction.

Figure 17d: *Skolithos ichnofacies* at Outcrop 8

Skolithos ichnofacies as in Figure 17d can be defined as straight vertical to slightly inclined cylindrical tube burrows. The burrow are straight, do not branch, cross, nor interpenetrate. Walls of burrow are smooth with structureless fill. The possible tracemakers of this type of ichnofacies are worms, phoronids, insect larvae, arthropods and small vertebrates. The *Skolithos ichnofacies* further confirms that this outcrop has the character of soft intertidal or shallow subtidal marine environments.

Figure 17e: Graded bedding of sandstone at Outcrop 8

Based on Figure 17c, we can see the coarser grain of sandstone deposited at the bottom followed by finer grains in the upward manners. This sedimentary structure is called graded bedding. Graded beds form when a steep pile of sediment on the sea floor or lake floor suddenly slumps into a canyon or off a steep edge. As the sediment falls, water mixes in with it, creating a slurry of sediment and water that flows quickly down a sloping bottom. When the flow begins to slow, the coarsest sediment is deposited first and progressively finer and finer sediment is deposited until finally the area sees only normal sedimentation again.

Figure 17f: Hummocky beds at Outcrop 8

Based on Figure 17f, we can see the hummocky cross stratification visible at Outcrop 8. Hummocky cross-stratification is a type of sedimentary structure found formed by the action of large storms, such as hurricanes. It takes the form of a series of "smile"-like shapes, crosscutting each other. Based on this evidence, we can confirm that Outcrop 8 is from shallow marine environment settings.

Figure 17g: *Glossifungites ichnofacies* at Outcrop 8

Based on Figure 17g, we can see *Glossifungites ichnofacies* visible at Outcrop 8. It is believed that this ichnofacies was formed by boring bivalves during ancient time. This represents the evidence that this outcrop is from marine intertidal and shallow subtidal zones.

Samples collected from Locality 8 (Kapilit)

Kp12a: Sandstone sample

Kp12b: Siltstone sample

Kp12c: Shale sample

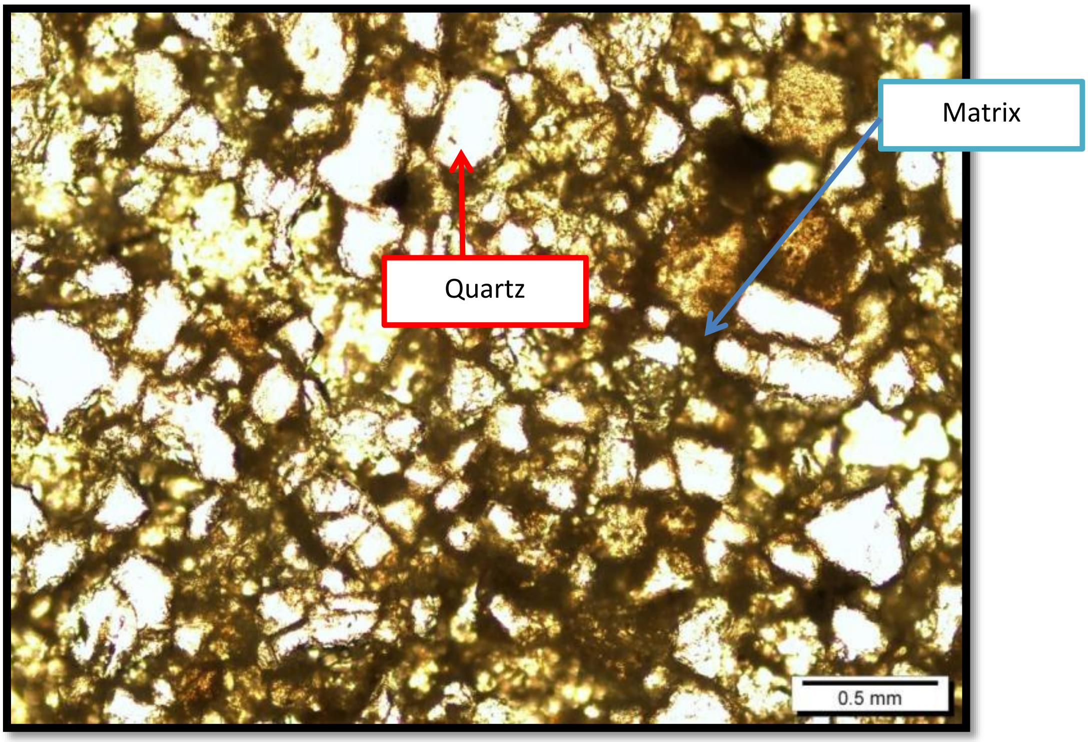
4.5 Summary of All Outcrops in relation to Sedimentary Structures and Environment of Deposition

Table below show the summary of every outcrops throughout the road traverse in relation to sedimentary structures found with its depositional environment.

Outcrop/Stops	Lithology	Evidences (sedimentary structures found)	Depositional Environment
1st Outcrop	1. Shale 2. Slate with Quartz 3. Siltstone		-Shallow marine, delta lagoon -low energy
2nd Outcrop	1. Shale 2. Red Clay	etc	Shallow marine, delta lagoon -low energy
3rd Outcrop	1. Shale 2. Unconsolidated Sandstone	etc	Shallow marine, delta lagoon -low energy
4th Outcrop	1. Sandstone with different grained size	-Load casts -Structural-Conjugate fractures	Shallow marine, delta lagoon -low energy
5th Outcrop	1. Shale 2. Unconsolidated sandstone 3. Massive sandstone	-Casts cylinder of burrows (skolithos/burrowing organisms)	Shallow marine, delta lagoon -low energy
6th Outcrop	1. Shale 2. Sandstone	-Load casts	Shallow marine, delta lagoon -low energy
7th Outcrop	1. Sandstone 2. Shale	-Load casts	Shallow marine, delta lagoon -low energy
8th Outcrop	1. Graded sandstone 2. Siltstone 3. Shale 4. Sandstone	-Skolithos -Glossifungites -Graded bedding -Hummocky cross beds	Shallow marine, delta lagoon -low energy -catastrophic events cause by hummocky

4.6 Thin Section Analysis

KB10 (Kalabakan) Plane Polarised 10x magnifying



KB10 (Kalabakan) Cross-Polarised 10x magnifying

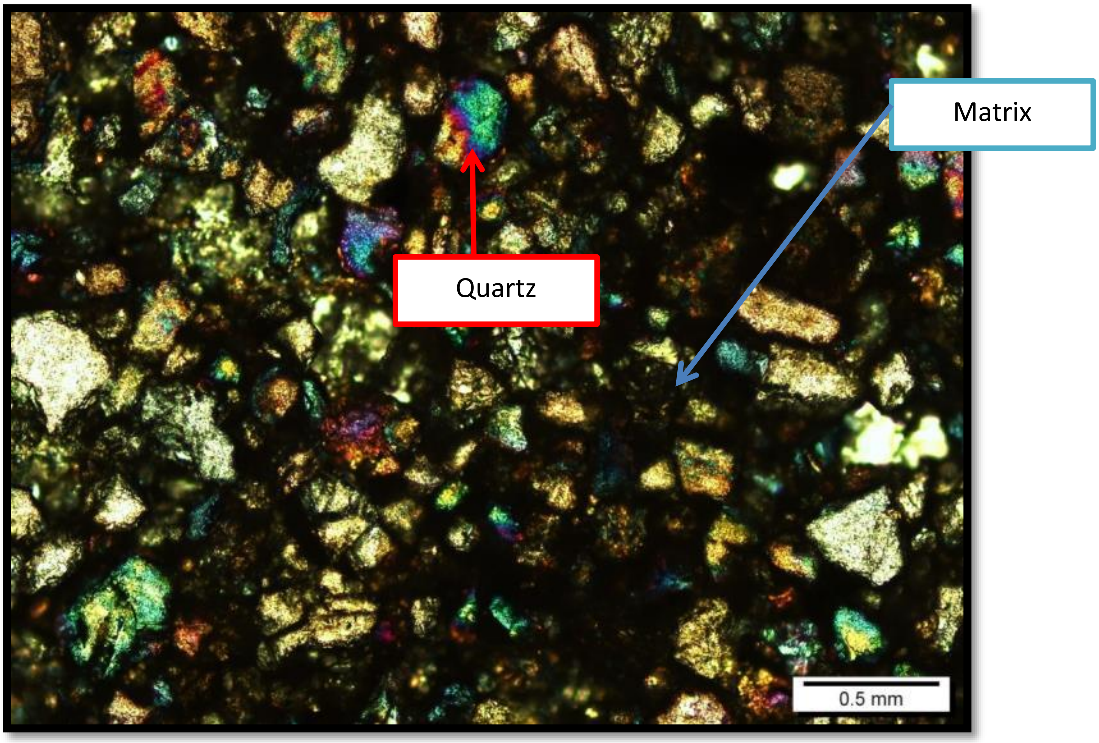
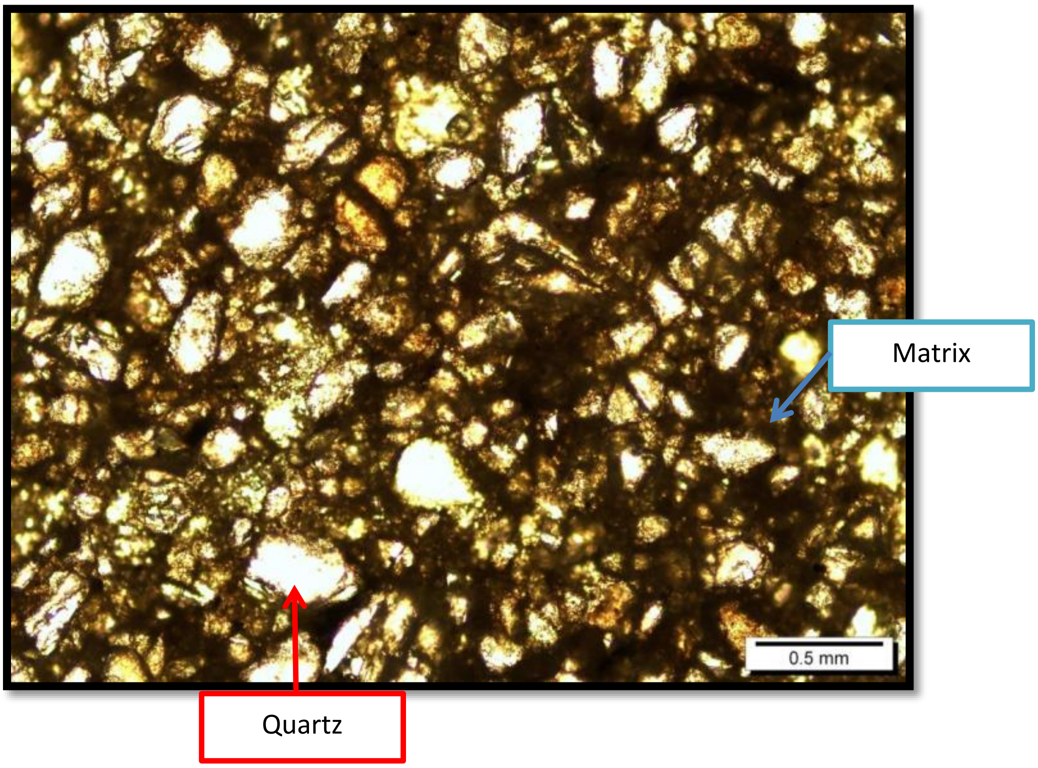


Figure 18: Thin section for Sandstone KB10 of Kalabakan

KP12a (Kapilit) Plane Polarised 10x magnifying



KP12a (Kapilit) Cross-Polarised 10x magnifying

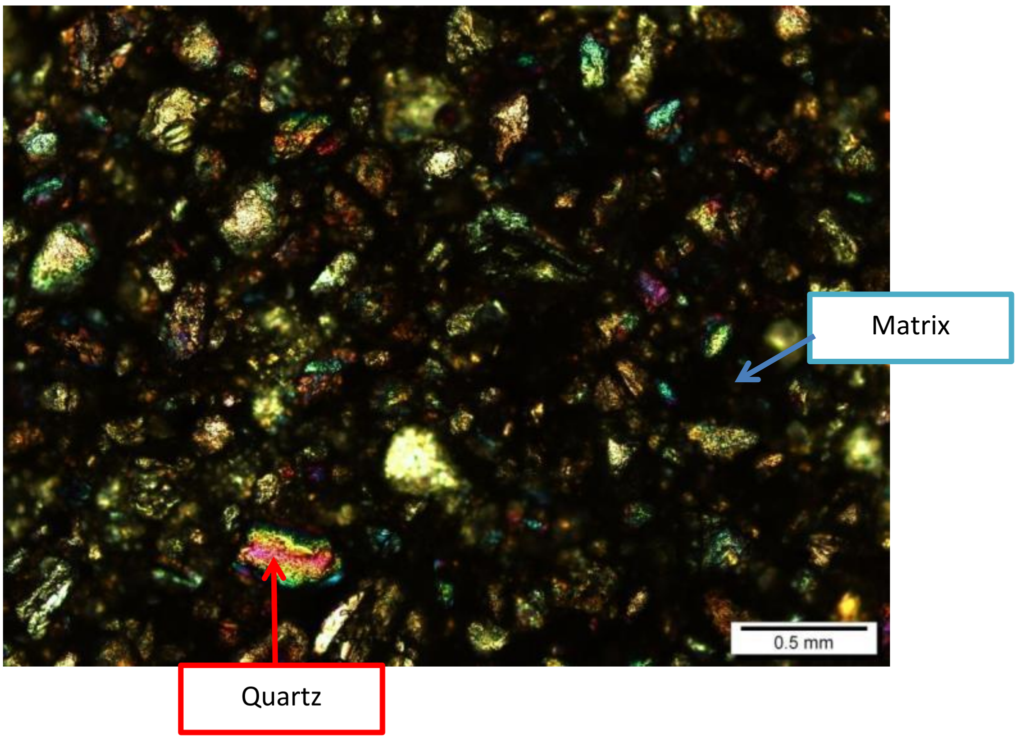


Figure 19: Thin section for Sandstone Kp12b of Kapilit

Summary on thin section analysis of Kapilit and Kalabakan samples Kb10 and Kp12b

1. Lithology: Sandstone
2. Grain size: Fine to very fine grain
3. Angularity: The grain has sub-angular to angular in shape
4. Rounded: The grain are rounded to sub-rounded in shape
5. Crystal system: Mostly Rhombohedral in shape
6. Ratio of Quartz to Matrix : For Kb10=40 to 45% Quartz to Matrix

   For Kp12b=65% to 70% Quartz to matrix

CHAPTER 5

CONCLUSION

In conclusion, after continuous months of efforts, this Final Year Project (FYP) has finally end with its early objectives has all been achieved. A detailed study of sedimentology and structural geology of Neogene formation specifically Kapilit and Kalabakan area has been conducted extensively. Through excellent guidance and supervision of lecturer during the fieldwork and discussion session, the structural geology and sedimentology of the area has been thoroughly understood. Thin section analysis has really help in term of understanding the mineral composition and grain size distribution in relation to the type of depositional environment. Lineament analysis of Sabah through satellite aerial images has been correlated whether it has coherency with the fracture/bedding data of the outcrops. The Kalabakan and Kapilit has been concluded as formations that vary from deep marine to shallow marine depositional environment with further been supported by presence of special sedimentary structures.

RECOMMENDATION

In order to get a better results and a clearer picture of future possible conducted project, there are several recommendations to be applied:-

I. Do more stratigraphic analysis of the area. Example- Comparison or correlation of separated strata which include study of lithology, fossil contents, and relative or absolute age, or lithostratigraphy, biostratigraphy and chronostratigraphy.
II. Do stratigraphic logs to relate lithology of the study area with tectonic history of Sabah.

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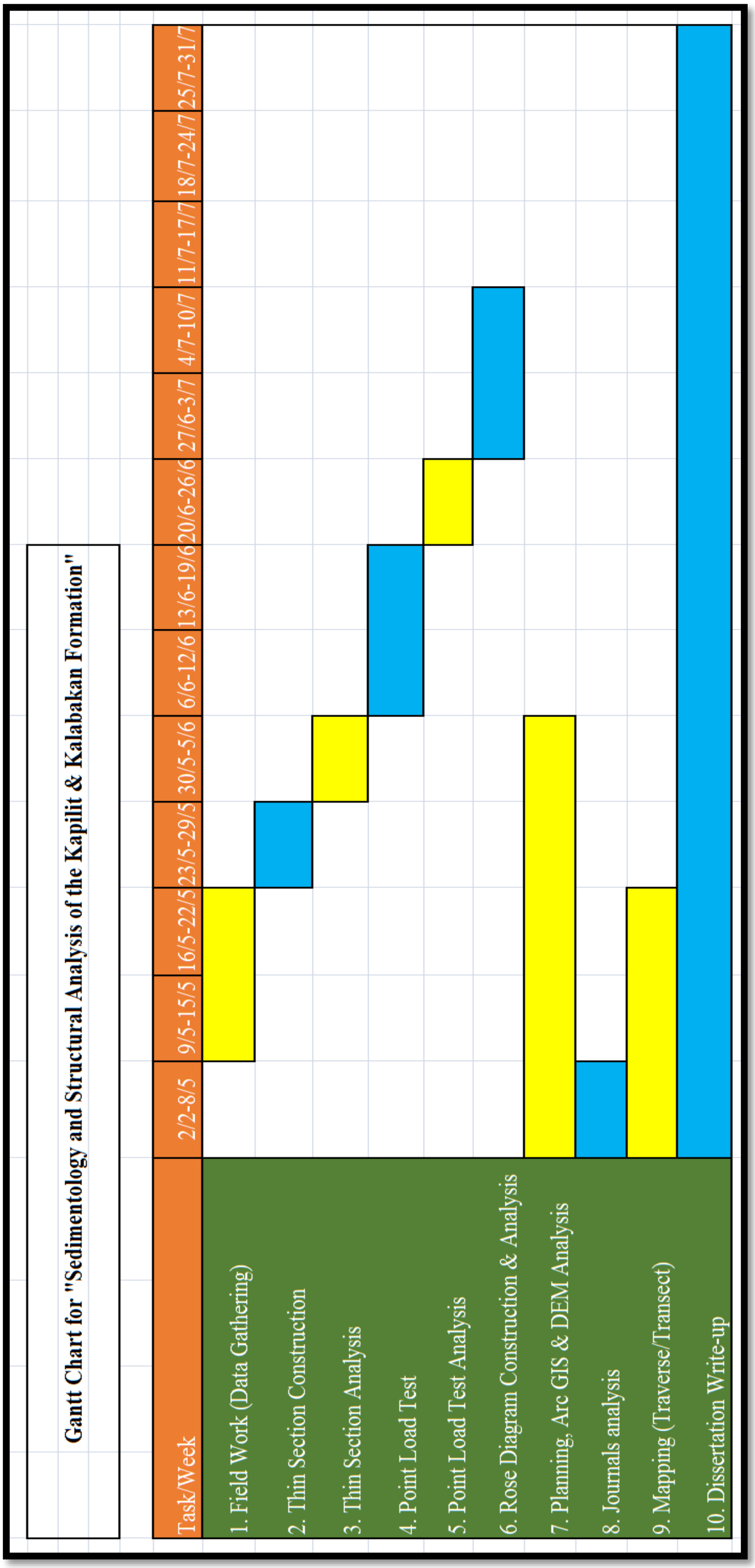
APPENDICES


Gantt Chart for "Sedimentology and Structural Analysis of the Kapilit & Kalabakan Formation"
Task/Week
2/2-8/5
9/5-15/5
16/5-22/5
23/5-29/5
30/5-5/6
6/6-12/6
13/6-19/6
20/6-26/6
27/6-3/7
4/7-10/7
11/7-17/7
18/7-24/7
25/7-31/7
1. Field Work (Data Gathering)
2. Thin Section Construction
3. Thin Section Analysis
4. Point Load Test
5. Point Load Test Analysis
6. Rose Diagram Construction & Analysis
7. Planning, Arc GIS & DEM Analysis
8. Journals analysis
9. Mapping (Traverse/Transect)
10. Dissertation Write-up